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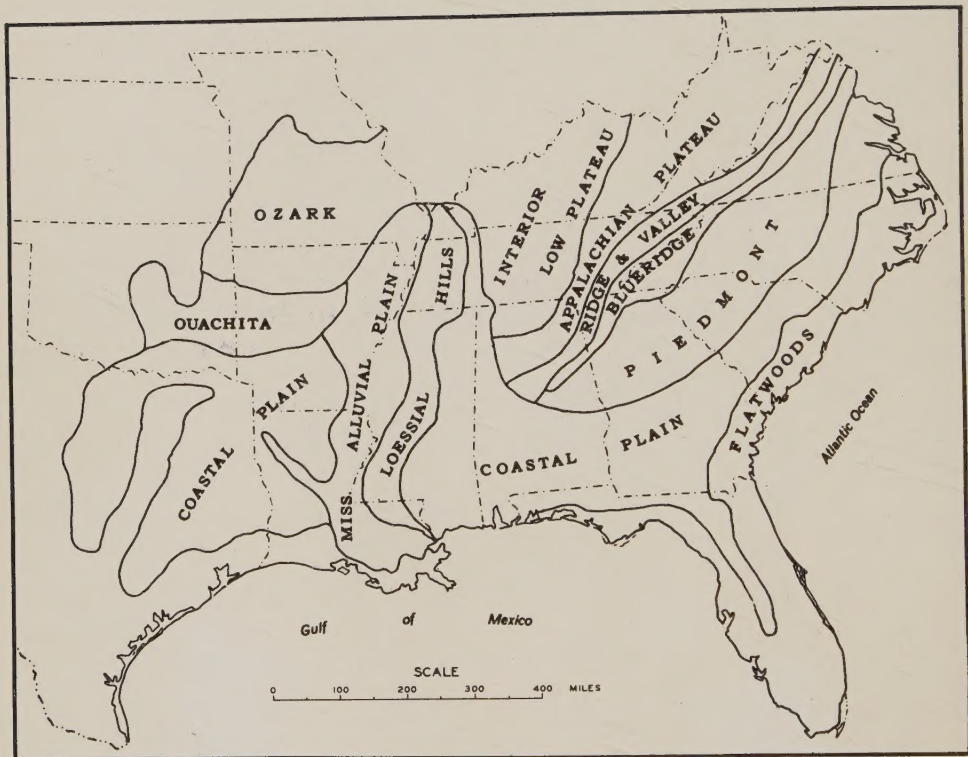
SOUTHERN FOREST SOILS

Figure 1. Physiographic regions of the South.

1959

8th ANNUAL
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SOUTHERN

FOREST SOILS

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FOREWORD

Each year, beginning in 1952, the Louisiana State University School of Forestry has sponsored a symposium in the subject of forestry, with the assistance of the General Extension Division of the University. The aim of these symposia is to bring practicing foresters in the South up to date on recent technical advances in forestry. Each symposium has a theme, chosen with the current interests of southern foresters in mind. Symposium themes in years past have been (1) young pine management, (2) the upland hardwood problem, (3) planting and direct seeding, (4) forest fires, (5) management planning, (6) bottomland hardwoods, and (7) insects, diseases, and wildlife.

The 1959 theme is southern forest soils. Interest in forest soils has developed rapidly in the last decade. As forest management in the South has become more intensive and as land prices have gone up, more soils information is needed. Practicing foresters desire to know the implications of recent soils research, some of which has not heretofore been published.

Speakers for the 1959 Symposium were carefully chosen. Each speaker is an expert in a specialty related to forest soils. The talks are reproduced here for the benefit of all who may be interested in the subject.

<div align="right">Paul Y. Burns</div>

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S. A. LYTLE, Department of Agronomy
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Soils are used by trees as places in which to anchor their roots and as sources of food and water. The capacity of a soil to supply suitable anchorage and sufficient food and water for tree growth depends largely upon the needs of the particular tree species and on the properties of the soil. More than half of the tree species of this country grow in our southern forests in many different soils having widely different properties.

Anchorage is of first importance to tree growth. Under certain conditions, deep sands are more readily penetrated by roots than clays. However, each of these sites provides favorable anchorage for some tree species. Tree roots may find anchorage in very shallow soils or in rock fissures, sites which are limited in their supplies of food and water. Flat, moist areas may be favorable sites for seed germination, but unfavorable for root growth of some tree species due to poor aeration and drainage. Many of our flatwoods soils have hardpan, claypan, and siltpan layers, which discourage the deep penetration of tree roots. Deep, well-drained, permeable soils provide suitable anchorage for many tree species.

Soils differ in the amount of moisture which they are capable of supplying to trees. Shallow soils on steep slopes may supply enough moisture for tree survival, but not enough for vigorous growth. Soils at the bases of long slopes generally contain more moisture than soils on upper slopes. Soils in coves and protected northern- and eastern-facing slopes are better supplied with moisture than soils on exposed southern and western slopes. Poorly drained soils at low elevations are generally too well supplied with moisture for some tree species. Soils which are well supplied with organic matter collect and retain moisture better than soils which are low in organic matter. In the area of southern forests, deep, well-drained soils on gentle slopes, having sandy clay, silty clay, or silty clay loam subsoils are capable of holding sufficient moisture for the growth of most plants.

Soils differ in the amount of plant food which they are capable of supplying to trees. Heavy clay soils do not permit the free penetration of the roots of many tree species. Therefore, the tree obtains only a part of the available plant food present in the soil. Many upland soils contain

low amounts of organic matter and mineral plant nutrients. Soils at high elevations in mountainous areas are generally well supplied with mineral plant nutrients and organic matter. These mountain soils remain frozen a part of each year, thus preventing the leaching and removal of plant food.

The southern forest area includes many kinds of soils which differ widely in their physical, chemical, and mineralogical properties. The soils have developed under forest in a climate which is generally warm, humid, and temperate. The major differences in the soils are due primarily to differences in the parent materials, in the relief and pattern of slopes, and in the length of time that the soil-forming processes have had influence on the materials.

The area of southern forest soils is separated into 11 land forms or physiographic areas, which represent the different units of landscape, such as plains, hills, plateaus, mountains, and valleys. Each physiographic area includes soils and soil materials of about the same kind and age, having about the same kind of properties, and occupying slopes having about the same range in shape, pattern, and elevation. The physiographic areas are outlined in Figure 1 (See front endpaper).

The following section includes a general description of each physiographic area and of the soils in each area.

Mississippi Alluvial Plain

This area of stream alluvium extends down the Mississippi Valley from Cape Girardeau, Missouri to the Gulf. It includes sediments deposited by the Mississippi River, Red River, and the major tributary streams. Low, narrow, natural levee ridges of better-drained soils occur along stream channels. The soils of the ridges are made up of silt loams, very fine sandy loams, and silty clay loams. The water table is usually 18 to 30 inches below the soil surface. The depressed and flat backswamp soils are generally poorly drained clays. Considerable areas of the clay soils are occasionally flooded where they are not protected by levees. The soils contain moderate amounts of organic matter and are well supplied with mineral plant nutrients. The soils generally range in reaction from slightly acid to alkaline. This is the important forest area of bottomland hardwoods.

Coastal Flatwoods

This lowland area of generally poorly drained soils occurs along the Atlantic and Gulf coasts on elevations ranging from sea level to about 50

feet. It includes interior areas of flatwoods in Alabama, Mississippi, and Louisiana. The soils of this area are formed from marine and stream deposits of sand, sandy clay, and clay of Recent and Late Pleistocene geological age, and from Pliocene sandy limestone and coralline limestone. The surface soils are generally gray silt loams and very fine sandy loams. The subsoils are gray or mottled sandy clays or clays, commonly having fragipan or claypan layers. Surface runoff and internal drainage are slow to very slow. The water table ranges from a few inches to as much as 2 feet below the soil surface. The soils are medium to strongly acid. They generally contain low amounts of organic matter and mineral plant nutrients. Trees commonly growing on the flatwoods soils are loblolly, longleaf, shortleaf, and spruce pines, water and blackjack oaks.

Loessial Hills and Terraces

The Loessial Hills are made up of soils which have developed from wind-deposited or stream-deposited silts of Late Pleistocene geological age. These sediments form a mantel ranging in thickness from 2 feet to more than 100 feet over unconsolidated sands, sandy clays, and gravels of earlier Pleistocene age. These silty materials occur in a relatively narrow belt extending from Louisiana to Illinois, and bordering the Mississippi Alluvial Plain. The soils occur on rolling and hilly areas, with steep slopes and escarpments around drains. Included with the Loessial Hills are the level and gently sloping terrace soils. Well-drained and moderately permeable soils generally occur on the sloping and hilly areas. The soils have brown silt loam surface soils and brown or yellowish-red silty clay loam subsoils, with good moisture holding capacity. Surface runoff and internal drainage are moderate. Imperfectly drained and poorly drained soils with slowly permeable subsoils occupy level and gently sloping areas. They have grey or brown silt loam surface soils and yellow mottled or gray subsoils with fragipan or claypan layers. The water holding capacity is generally low. The Loessial Hills and terrace soils are medium to strongly acid. They are generally low in organic matter and mineral plant nutrients. The forest cover generally includes oak, hickory, and shortleaf pine trees.

Coastal Plain Uplands

The Coastal Plain Uplands occupy a broad belt of relatively low land, 100 to 300 miles wide, along the Atlantic and Gulf coasts, and along the former coastline of the embayed section of the Mississippi Valley. This area lies inland from the Coastal Flatwoods. It occurs on elevations rang-

ing from 50 feet to more than 600 feet. The area is made up of uncon-
solidated marine and stream deposits of sand, silt, clay, and gravel. These
sediments represent several geological terraces of Pleistocene age. Each
Pleistocene terrace represents an emerged continental shelf which has
been exposed or elevated to its present position by uplift of the land
area or by lowering of the sea level. Relief of the Coastal Plain Uplands
ranges from gently rolling to rolling and hilly. The soils developed from
these unconsolidated sediments are generally sandy, permeable, and well
drained. The surface soils are gray or brown sandy loams. The subsoils
are brown, yellow, or red sandy clay loams or sandy clays. Considerable
areas of clay soils also occur in the area. The soils are medium to
strongly acid and low in organic matter and mineral plant nutrients. The
water holding capacity ranges from moderate to low. The principal trees
of the Coastal Plain Uplands are longleaf, shortleaf and loblolly pines,
oak, gum, and hickory.

Ouachita Province

The Ouachita Province includes the Ouachita Mountains and the Ar-
kansas Valley of central western Arkansas and eastern Oklahoma. The
mountains were carved by erosion from closely folded, faulted, and ele-
vated rocks, primarily sandstone and shale, ranging in geological age
from the Cambrian to the Pennsylvanian. Elevations range from 250 feet
to more than 2000 feet. The Arkansas Valley section includes the fertile
alluvial plain of the Arkansas river and the adjacent valley slopes and
low mountains of sandstone and shale of the Pennsylvanian. Shallow
cherty and stony soils with low moisture holding capacities commonly
occur on the rolling, hilly, and steep slopes. These soils are well drained
to excessively drained. Smaller areas of deeply developed well-drained
soils occur on the broader ridge tops. These soils are capable of holding
fair to moderate amounts of water available to plants. In general, the
soils of this area have brown or grayish brown friable sandy loam surface
soils and brown sandy clay or silty clay subsoils. They are medium to
strongly acid. The content of organic matter and mineral plant nutrients
is generally low. Forest trees growing in this area include shortleaf and
loblolly pines, oak, and hickory.

Ozark Plateaus Province

This area of dissected plateaus includes rolling high lands, valleys, and
belts of rough dissected land located in southern Missouri and northern
Arkansas. The Boston Mountains of northern Arkansas and northeastern

Oklahoma make up the southern boundary of the province. The province includes nearly horizontal beds of limestone, cherty limestone, dolomite, sandstone and shale ranging in geological age from the Cambrian to the Mississippian. Elevations are 400 to 1700 feet. The Boston Mountains, a remnant of Pennsylvanian sandstone left after the general denudation of the Ozark Plateaus, have elevations of 2250 feet. In general, the soils developed for the disintegrated rock materials are shallow and contain much chert and sandstone rock. They are freely permeable and the moisture holding capacity is low. Fairly deep, permeable soils with good moisture holding capacity have developed on rolling high lands and broad ridges. They have grayish brown, gray or brown silt loam, cherty silt loam, or sandy loam surface soils and brown or yellowish brown silty clay, clay, or sandy clay subsoils. Imperfectly-drained and poorly-drained soils with hardpan layers and low moisture holding capacity have developed on some broad, flat ridge tops. The hardpan layer hinders the downward movement of water during wet periods and hinders the capillary rise of water when the upper soil layers are dry. The soils of this province are generally low in organic matter and mineral plant nutrients. They are medium to strongly acid. The dominant trees of this province are shortleaf pine, oak, hickory, and red cedar.

Appalachian Plateaus Province

This province includes plateaus of nearly horizontal rocks, chiefly sandstone and shale of the Pennsylvanian age, which extend from northern Alabama into West Virginia and include parts of eastern Tennessee and Kentucky. Erosion has carved the uplifted rocks into smooth-topped mountains, elongated ridges, hills, steep slopes, and escarpments. The province includes the Cumberland Plateau, having elevations of 700 to 2200 feet, the Appalachian Plateau at elevations of 1500 to 3000 feet, and the Cumberland Mountains, 2500 to 4000 feet. The soils have developed from materials weathered from sandstone, shale, limestone, and conglomerate. They are dominantly well-drained, permeable, shallow soils on steep slopes. Their capacity to store water for plants is generally low. They are medium to strongly acid and low in mineral plant nutrients and organic matter. Areas of deeply developed soils on gentle slopes have good moisture holding capacity. The surface soils are dominantly gray or grayish brown friable silt loams or very fine sandy loams. The subsoils are red, brown, or yellow permeable sandy loams, sandy clay loams, or silty clay loams. Common tree species growing in this province are oak, yellow poplar, hickory, and shortleaf pine.

Interior Low Plateaus Province

This province includes plains and domes developed on old, well-indurated rocks ranking in geological age from the Ordovician to Mississippian, located in northern Alabama, western Tennessee, and western and central Kentucky. The province includes the Highland Rim section of Mississippian rocks, chiefly limestone, the Nashville Basin and Bluegrass sections, low domes which have been truncated to expose Ordovician phosphatic limestone and Silurian limestone, and the Shawnee section, a shallow syncline of Pennsylvanian sandstone. The plateaus range in elevation from 600 to 1300 feet. Permeable, well-drained soils have developed on the rolling, hilly, and steep areas. Many of the soils are shallow and cherty. They have brown or gray silt loam, cherty silt loam, or sandy loam surface soils and red or brown firm to friable sandy clay loam, silty clay loam, or clay subsoils. The capacity to store moisture is medium to low. The soils are medium to strongly acid. They contain moderate to low amounts of mineral plant nutrients and organic matter. Deep soils developed from materials weathered from phosphatic limestone contain moderate amounts of organic matter and are well supplied with mineral plant nutrients and moisture. Soils with hardpans occur on some gently sloping areas. The major tree species of this province are oak, hickory, and shortleaf pine.

Ridge and Valley Province

This area is characterized by parallel ridges of sandstone, shale, and conglomerate, separated by valleys of less resistant limestone and shale. The province lies between the Blue Ridge Mountains on the east and the Appalachian Plateaus Province on the west. It extends from northeastern Alabama and northwestern Georgia, across eastern Tennessee and western Virginia. The form of this province is due to the differential erosion of severely folded and faulted rocks ranging in age from the Cambrian to the Pennsylvanian. The valleys occur at elevations of 400 to 2400 feet and the ridges are 1300 to 4000 feet high. The area includes gently sloping valleys and rolling and steeply sloping ridges and ridge slopes. The soils developed from the weathered rock materials are generally moderately permeable and well to excessively drained. The surface soils are gray, brown, or red silt loams, sandy loams, and silty clay loams. The subsoils are red or brown friable silty clays, clays, or sandy clay loams. Deeply developed soils on gentle slopes of the limestone valleys are medium to strongly acid and contain moderate amounts of organic matter and mineral plant nutrients. They have fairly good moisture holding

capacities. Cherty and stony soils commonly occur on steep slopes. They are low in organic matter and mineral plant nutrients. These soils are freely permeable and the water holding capacity is low. The usual forest trees of this province are oaks, hickory, shortleaf and loblolly pines.

Blue Ridge Province

This is a narrow to broad range of mountains in northeastern Alabama, northwestern Georgia, western North Carolina, South Carolina, and western Virginia. The mountains are made up of old, highly complex Cambrian and Pre-Cambrian igneous and metamorphic rocks, chiefly granite, schist, gneiss, and quartzite, with some dark-colored basic igneous rocks. The area includes rough, hilly, and steep slopes at elevations of 1400 to more than 6600 feet. The soils formed from materials weathered from these resistant rocks are generally well to excessively drained. Soil profiles are moderately well developed, usually to depths of 20 to 30 inches. Large areas of more shallow soils occur on steep slopes. The surface soils are brown or gray loams or sandy loams containing moderate amounts of organic matter. The subsoils are red, brown, or yellow friable clay loams or clays. The deeply developed soils have good water holding capacities. The shallow soils are low in water holding capacity. The soils are medium to strongly acid. They contain moderate amounts of mineral plant nutrients. The forest cover includes oak, hickory, yellow poplar, and shortleaf pine trees.

Piedmont Province

This is a plain or plateau formed by the repeated uplift and degradation of highly complex igneous and metamorphic rocks. It represents the floor of an old plain which has been uplifted to its present position above sea level. It is an eastern extension or seaward portion of the Blue Ridge Mountains which has been reduced to a peneplain. The area extends from eastern Alabama into northwestern Georgia, and western North Carolina, South Carolina, and Virginia. Elevations range from 400 to 1800 feet. The Piedmont is generally higher than the Coastal Plain Uplands on the east and lower than the Blue Ridge Mountains on the west. This province is made up of some of the oldest rocks in this country, the Pre-Cambrian granites, gneisses, schists, and some dark-colored basic igneous rocks. Long and intense rock weathering has produced a thick mantel of decayed rock materials, which cover the rocks in most places. The province is thoroughly dissected and slopes are undulating, rolling, and steep, with rough broken areas along streams.

Included with the Piedmont Province are the Piedmont Lowland and the Carolina Slate Belt. The Piedmont Lowland is a basin-like area of undulating to hilly relief, underlain by Triassic shale, mudstone, and sandstone. It occurs in central and northern North Carolina and southern Virginia at elevations of 350 to 600 feet. The Carolina Slate Belt is an area of Ordovician black shales and some dark-colored basic igneous rocks. It occurs on undulating, rolling, and steep slopes, and extends from Virginia across North Carolina and South Carolina into eastern Georgia.

The soils of the Piedmont are generally well drained and medium to strongly acid. The surface soils are sandy loams, clay loams, or silt loams. The subsoils are red or yellow, firm to moderately friable clays or sandy clays. Deeply-developed soils capable of storing ample moisture for most plants occur on gently sloping and rolling areas. On steeply sloping areas, the soils are generally shallow and the moisture holding capacity is low. The soils are generally low in organic matter. They contain moderate to low amounts of mineral plant nutrients. In general, the forest cover includes oak, hickory, yellow poplar, and shortleaf pine trees.

PHYSIOLOGICAL RELATIONSHIPS OF SOILS TO FOREST GROWTH: RESEARCH IMPLEMENTATION

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The present status and trends of research involving physiological relationships between soils and forest growth have been presented ably by Coile (1952) and Wilde (1958). In addition, recent symposia have been concerned with forest physiology and tree nutrition. Much of this information, however, "misses the mark" with forest land managers because it is not related to specific silvical problems in a given forest region. The articles by Kozlowski, for example, together with his bibliography of tree physiology (1956) contain some very significant contributions to our understanding of physiological relationships between forest soils and forest growth. Shaw (1952), Levitt (1956), and Thimann (1958) are excellent sources of reference material in this field. This literature presents a very real challenge to the forest researcher, for the answers to many silvical problems rest in his ability to interpret such fundamental works.

A large proportion of the research in forest-soil relationships has been contributed by men who are not foresters—men who touch upon forest research via other basic and applied sciences such as plant ecology, plant physiology, soil science, and agronomy. For this reason, few of our concepts in this field have come to us from conceptualized forestry studies where all the factors of plant environment and growth are considered. Rarely do we get a glimpse of a developmental sequence of studies that starts from a broad base in a given region, and progressively narrows down to facets that are encompassed within the severest definition of fundamental research. Hence, much of the supportive literature seems fragmentary or unrelated except as it fits into topics or chapter headings that have been used for years in forestry texts.

We can no longer afford to consider research in forest physiology and soils as a series of interesting academic abstractions. It is time to begin interpreting these abstractions in terms of current and anticipated silvicultural problems. The major research need of our time is for qualified

interpreters who can develop a sound framework within which related studies can be pushed farther and farther back into the fundamental disciplines.

Conceptualized and Programmed Research

Billings (1952) presented a strong case for the concept that all factors of environment that influence plant growth for a forest region should be considered together—the holocoenotic environment. This approach was used by the Missouri Agricultural Experiment Station in an effort to define some silvical problems in the Missouri Ozarks. Existing (secondary) data provided the basis for an hypothesis. Subsequent field observations modified it, and later studies have begun to define more intensive physiology and soils experiments, still in progress.

Shortleaf pine (*Pinus echinata* Mill.) was selected as the species around which to develop the first research parameters. Ultimately other species will be similarly studied. The goal, of course, is to provide a scientific basis for our silvicultural practice. The principles, and the approach, may have value to workers elsewhere.

At the outset, a careful study was made of the map showing the distribution of shortleaf pine in Missouri, as reported by Liming (1946). A southern species, shortleaf pine reaches its northwestern extremity in southern Missouri. Why does its natural botanical range stop where it does? As it approaches its range extremities, why does it occur in disjunct patches?

The first indications of broad environmental correlations became apparent when the distribution map of shortleaf pine was compared with distributional patterns of major geologic formations and soil series (Clark, 1939; Miller and Krusekopf, 1931). Especially noticeable was the lack of pine on deposits of loessial materials as depicted by Thorp, Smith *et al.* (1952). Through long conferences with colleagues in other disciplines, it became evident that, in the main, shortleaf pine occurs where sandstone, sandy dolomite, or granite-porphyry are the underlying rocks. Pine is especially prominent as a component of the prevailing oak-hickory association where the Roubidoux sandstone formation is strongly dissected by rugged relief. Surrounding much of the Ozark pineries of Missouri is a belt of gentle relief on limestones and dolomites, notably the Jefferson City formation, which rarely supports pine.

These geologic-soils criteria provided satisfactory relationships, in the main. However, one major exception was found where the environmental conditions seemed favorable, but no natural stands of pine have ever been known. This exception is the Lake-of-the-Ozarks country, typified by

rugged terrain in Roubidoux sandstone, some 75 miles northwest of the natural pine range. An explanation may well lie in an interpretation of climatic variations, as reported by Decker (1955) and Collier (1955). It appears that critical precipitation and temperature relationships occur during the period November through April. When isohyet lines of precipitation are drawn for this period, they make a rather precise northeast to southeast pattern across the state, ranging from 10 inches in northwestern Missouri to 26 inches in southeastern Missouri. The 17-inch isohyet closely approximates the northern extremity of shortleaf pine in the state, and the Lake-of-the-Ozarks, to the north of this line, lies in the 15-inch isohyet of winter precipitation. Thus, it appears that winter precipitation and temperature become increasingly critical (limiting) factors as the northwestern limits of the range of shortleaf pine are approached. A remark by Kramer[2] that "shortleaf pine doesn't like to get its feet wet" seems to be as apt for Missouri planosols in winter, as it may be for Piedmont claypans in early summer. The significance of poor internal drainage and temperature as they seem to limit occurrence, growth, and development of shortleaf pine has been pointed out by Reed, Kramer, Coile, Kozlowski, Zahner, Hocker, Copeland, and many others.

The establishment of these parameters was made possible by a wealth of good secondary data, gathered over the years by our colleagues in geology, soils, and climatology. A good backlog of research in forest physiology and forest sociology was essential to an interpretation of these "abstractions" into a forestry context.

Of special interest in silvicultural practice is the interpretation of why shortleaf pine occurs where it does. The evidence gathered by Fletcher and McDermott (1957a) supports the view that the species is sub-climax in Missouri, maintaining its greatest stability on sites which it tolerates somewhat better than its hardwood associates. Thus, the Clarksville stony loam soil derived from the Roubidoux sandstone formation, "containing much chert, with a variable sandstone content, and on rolling to steep terrain is actually drouthy. Pine did, and still does, occur here simply because it is better able to grow here than its hardwood associates. Given full sunlight, as on a south and west-facing slope, it is especially well adapted to grow (and regenerate) under these relatively xeric conditions . . . . It may grow faster and taller on . . . . better sites, but these are proportionately better for the oaks, and (on them) seedling pines cannot meet the competition of oak sprouts."

Of eighteen soil series now recognized within the range of shortleaf pine in Missouri, ten are generally off-site for pine management, being

[2]Kramer, P. J. (1956). Discussional comment, meeting of the Ecol. Soc. Amer. AIBS, Storrs, Conn.

either excessively well-drained, or having poor internal drainage. Four are better adapted to cultivated crops or hardwoods, although capable of producing tall pine trees. The added cost of controlling hardwoods to encourage pine on these soils may not be justified. Between these two extremes are four soil series on which pine is indicated in the forest management type.

These broad silvical parameters for shortleaf pine in Missouri are well fixed, and serve as a model for several related studies of hardwoods. Scarlet oak, southern red oak, and cherrybark oak are other important southern timber species that may reflect some combination of environmental factors that limit the degree of northern extension into Missouri.

An understanding of the broad environmental relationships provides a strong basis for conceptualizing specific studies hinging on forest composition and growth as related to physiological relationships of soils. Fletcher and McDermott (1957b) in a further study observed that the significance of a loess cap of either river or great plains origin lies in the typical development of a claypan or fragipan in the lower subsoil. Where this soil occurs on gently rolling or level terrain, the soil moisture ranges from constant supersaturation (waterlogged) throughout the winter and spring to sustained wilting percentage through the summer and fall. Current experiments are under way to ascertain the joint relationship of drouth hardiness and saturation hardiness of the major Ozark timber species. It has become apparent that present methods of measuring drouth hardiness are quite inadequate. Intensive studies are needed to evolve precise techniques for measuring the relationships of this growth factor under field conditions. Paradoxically, saturation tolerances will require additional concurrent methodology and interpretation studies to evaluate this phenomenom as it affects forest composition and subsequent growth.

Present site evaluation work is largely adapted from Coile's procedures with the additional features of sampling stratified by geologic formations, soil series with phosporus breakdowns, and precipitation-temperature isohyets.

Each segment of work undertaken and completed provides the basis for additional more intensive definitions of increasingly precise studies involving the physiological relationships of soils to forest growth. In some respects this research approach resembles the "why-oriented" concept recently discussed by Stone (1957).

What is a Forest Physiologist?

A great storehouse of secondary (across discipline) data exists that may be applied to silvical problems as exemplified by the foregoing illustration.

Many if not most of these contributions have come from plant physiologists, plant ecologists, horticulturists, agronomists, etc. However, as the precise definitions of specific problems emerge from successively smaller field-derived parameters, there also emerges the need for fundamental or basic studies by researchers with a forestry background who can document the broad field problems from a forestry viewpoint and then program the various research fasciations to solutions. It is fortunate that there are fine research people in the basic disciplines who touch on forestry problems from time to time. They make additional contributions that provide a basis for interpretation of our problems in forestry. A forestry background with the documentary and implementation skills that are characteristic of the profession provides a basis for guiding and directing fundamental research. So directed, the research results and interpretations are freed from the abstract connotation of the literature cited by Kozlowski (1956).

The forest physiologist must be well versed in plant physiology and soils and have a wide reading knowledge of the literature in these basic areas and their applied fields. It is a great shock to learn that the broad question you have been belaboring for months was resolved and generally accepted by the horticulturists 30 years ago. As Schilling (1958) has observed, science is a social enterprise, augmented by interpersonnel exchanges and checks in the confirmation and testing of truth. This, of course, opens up another big discussion on the dangers of a stereotyped approach that can accompany conceptualized research models. Also, the question of the team approach versus the individual researcher is a big and complex subject. The question that emerges here, however, is, as we narrow the parameters of our research problems, at what point do foresters carry out some of their own basic research? Or, do we proceed to certain research platforms and then wait for the fundamentalists to slowly evolve solutions for us?

Currently there are strong winds blowing, extolling the need for basic research. Other than present international motivations for defense and the conquest of space, it is difficult to see why basic research should suddenly become the vogue and why the need wasn't just as clear ten, twenty, or thirty years ago. Nevertheless there seems to be a belated note of "us-tooism" in forestry. Such catchy little phrases as "the great need of basic research in silviculture" are bandied around. Does someone really believe that research personnel in broad silvicultural activities are suddenly supposed to "don white laboratory coats and turn to"? If we are to do fundamental research in conjunction with our silviculture it would appear that a real opportunity exists in conceptualized studies where recognition is given to the fact that forestry is not a fundamental science, but rather

an applied field of many disciplines fundamental to us. The implementation of research across disciplines is the potential great strength of forestry research units attached to colleges and universities, as pointed out by Westveld (1954). Here are representatives of the disciplines we are attempting to be basic in and the cumulative experience of these men, as their knowledge of the literature in their fields, are sources of great help and inspiration in our forestry research.

As the parameters of research narrow down to the basic research tenets of plant physiology and soil science, the developing complexity of these two disciplines make it increasingly difficult for the forest researcher to keep abreast of these dynamic fields. Over and above the complexities of the philosophy and methodology of these two groups is the tremendous development of automation or instrumentation of laboratory techniques. We read and hear about elaborate instrumentation techniques for protein analysis involving electrophorectic studies, ultra centrifugation, gas chromatography, etc. In soils we are impressed by the great research potentials of bioclimatic chambers, mass spectrometers, x-ray and electro-chemical methods of measuring ion-root interactions, etc. Indeed, a visit to one of these laboratories gives one the uneasy feeling that he should have picked up a degree in electronic engineering along the way somewhere. Items costing five to ten thousand dollars will of necessity become relatively common apparatus in our *point of origin* laboratories in a few years. Very complex, very expensive pieces of apparatus might best be located in centralized laboratories adjunct to or in association with our forestry laboratories.

It is frustrating to the forest researcher to realize that the philosophy and methodology of the basic sciences are changing so rapidly that he can't get really up to date in his own techniques. If the value of our research can be enhanced by cutting across disciplines, at what point can we make contributions to these fields as well as to our own? Or, must we continually rework the secondary data of these disciplines and confine our definition of fundamental research to this? Ideally, we should do both. The forest physiologist should resist the temptation of ultra-specialization in one portion of a given discipline. He should certainly refrain from becoming a technical expert in tracing circuits and making adjustments in the complex gadgetry of instrumentation. Nevertheless, the biochemical specialist has a very important place in our research. It is unlikely that the biochemist will often get into the woods (if he ever was a forester), because he is likely to have time-consuming problems within his own area. On the other hand, when the final interpretation of basic forestry research rests in biochemistry, it is obvious that the forest physiologist should encourage the biochemist to join him in the generation of new ideas.

Undergraduate Background for Graduate Work

At universities and colleges, one way to keep abreast of developments in related fields (in contrast to the customary slow seepage through the literature) is by means of graduate students. With the documentary skills of forestry, learned as an undergraduate, and with silvical research parameters explained to him by his advisor, this bright young man is a means of implementing near-basic and basic research.

There may be a need for some re-evaluation of the current status of graduate students and graduate student training. There is one institutionalized view that a Ph.D. candidate never quite reaches the great height of that institution, and most certainly not that of the professor with whom he is majoring. It could be argued that if the student doesn't comprehend more about certain disciplines than his major professor he is not developing properly, and supportive courses in basic disciplines are merely a series of obstacles to be overcome before awarding the degree. It might be that in some instances the advisor doesn't really believe in the importance of a series of courses in chemistry and has no thought of ever programming them into research, but somehow he knows that these courses are good for the student. To a degree, perhaps, the major professor should find himself sitting on the sidelines admiringly watching his boy's progress. His principal role might best be defined as maintaining direction and bolstering the enthusiasm level, tempered by a critical eye on the operations budget.

In some respects the master's degree has degenerated into a little nicety that students and faculty indulge in. Depending upon the intensity of the fundamental nature of the work contemplated, considerable time is devoted to courses that might better have been taken for undergraduate credit. In fact, it is all too often necessary to go back into chemistry, mathematics, botany, and soils courses that commonly carry no graduate credit. For this reason the dedication and interest of students interested in careers in research involving physiology and soils might best be cultivated at the beginning of the upper-class level.

In the colleges and universities where we prepare men for careers in forestry, the romance of the outdoors and the sense of "doing something for society" diminishes and is replaced by a feeling of accomplishment as each semester or quarter of the carefully calculated and planned curriculum is "logged off." While our curricula are carefully rounded out in botany, soils, geology, chemistry, and physics, these subjects become somewhat relegated to rather vague abstractions that someone has dictated as necessary for a degree. They are considered as entities in themselves by many students. These courses tend to have just a vague reference to

forestry. The hard core emerges in the upper class years as mensuration, silviculture, management, and utilization. And, this is as it should be within the concepts of our professional status.

Those of us in teaching are continually concerned with the degree to which the men from our own institution can measure up to the graduates of other institutions. We tend to hammer on the documentation and implementation skills of the profession. While the value of strong professional training to this end cannot be minimized, it is for this very reason that we tend to overlook the opportunity and value of research to the students. At what point in our undergraduate instruction dare we suggest that there are challenging unanswered questions in such areas as physiology and soils? It has been argued that if juniors are taken into the realm of speculation, or are prompted to question or qualify the authority of our texts, they get confused and do not have sufficiently mature judgement to cope with this type of presentation. Certainly students want good, hard, pithy facts that they can reproduce faithfully on quizzes. This type of presentation has many values, including the development of dogged tenacity and mental discipline, which are necessary and admirable traits. Also, it must be recognized that the teacher cannot sell the need of learning scientific nomenclature and phylogenetic relationships of trees. Rather, he insists that the student sell himself. Where, however, can we pique the imaginative mind so that a student can recognize that he doesn't have to be a rocket engineer or space scientist to be part of an exciting, challenging field? This has been pointed up by the current Rockefeller Report On Education (1958) as the identification and guidance of able students, while challenging each student to his full capacities. Perhaps, at times, we are too quick to use canned, tried and true "handouts" that are calculated to present little or no controversy. This is a tempting device when classes are large and one instructor has a variety of courses. Under these conditions, he has little or no time to prepare for straying beyond the immediate authority of available texts.

At the University of Missouri a serious attempt is made to incorporate research proposals and results into silvics and silvicultural instruction. As soon as research develops to the extent of definite parameters, it is presented to rising juniors in the instruction at summer camp. Part of this has been prompted by the enthusiasm of instructors with a captive audience. In any case, an attempt is made to demonstrate to the students the inadequacies of our present information, which result in "rule of thumb" procedures for some of our silvicultural practices.

There have been some indications of success from the standpoint of student reaction. Many of the men grasp that our sciences are evolved haltingly, circuitously, often illogically, with many false starts, as Schil-

ling (1958) has observed. We are gratified by a noticeable change in attitude of some students toward chemistry and mathematics. There is at least some recognition that much of our work hinges on biochemistry, and that as tedious and abstract as the lower chemistry and mathematics courses seem to be, they are very necessary for sound preparedness in a career of silvical research. Thus, beginning in the first semester of the junior year it is possible to use the electives through the senior year to obtain additional mathematics through calculus and chemistry prerequisites to physical chemistry. Now, if a particular student decides to go on into graduate work he has an excellent background in the tools that are requisite to plant physiology, soils, genetics, etc. over and above the excellent forest documentation skills he receives as an undergraduate. In his graduate program he may have to take some supportive courses for no credit, but if he needs more math or chemistry for continuation in physiology or soils he can take these courses for graduate credit as part of his graduate program. This background provides the basis for a strong and serious master's program.

For the majority of students who do not consider research as a career, (because of disinclination or grade-point limitations) it is hoped that a feeling of tolerance for research is instilled in them. At least, they should recognize that the cherished concepts of today are not unchangeable, but, rather, the best we have for now. Such a view is in sharp contrast with one recently expressed in the Journal of Forestry in which the writer wanted more trade news instead of the never-ending, presumably impractical, technical articles. The attitude of anticipating change seems well worth cultivating in upperclass, undergraduate students.

Summary

By way of summary, a great opportunity exists in interpretational studies designed to bridge or pull together the fragmentary supportive literature in physiological relationships of soils to forest growth. This might best be accomplished by conceptualized studies that define broad silvical field parameters and successively narrow down to faceted, ultra-basic research. As the research concepts narrow, the need for familiarity with the basic science disciplines becomes increasingly apparent.

Forestry research administered through an agricultural experiment station has a great potential in the interdiscipline approach via graduate student liaison with the ever-changing philosophy and methodology of these disciplines.

The undergraduate forestry degree with its excellent documentary skills provides a strong, bridging background for graduate studies in the basic

sciences of plant physiology and soil science. The stimulation of able students to become aware of research challenges in these areas might best be made at the beginning of the junior year, so that selection of appropriate elective courses can provide the background requisite to a strong master's program.

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HYDROLOGIC PROPERTIES OF
SOUTHERN FOREST SOILS

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The hydrologic characteristics of a soil, forest or agricultural, are those concerned with the movement of water into and through the profile, as well as the amount of water that can be stored in the soil. These properties of the soil are important because they deal with water—a substance necessary for plant growth yet limited to a definite supply. And since this supply often comes at irregular intervals it is desirable to keep the land in such a condition that the soil will take in and store a maximum of water for plant use. The properties of forest soils which regulate movement and storage of water are also important to stream flow because just about 60 percent of the land in the southern states is covered by forest growth. The forests of the South help maintain and build desirable properties in the soil and protect much of the land which contributes water to our many streams.

Is there enough water falling on the land so that good growth can be realized on this 60 percent of the land covered by trees? The average annual precipitation for the South comes out to about 50 inches—a quantity which certainly should be enough for any native vegetation. The only trouble, and this is often a big trouble, is that the water is not always in the soil when the vegetation needs it. Lack of adequate moisture during the growing season probably causes the timber grower more loss of growth than any other single factor.

Let's follow the annual rainfall and see just what happens to it. Weather stations measure rain in the open but since foliage intercepts water, much of which is subsequently returned to the air by evaporation, we find that part of the 50 inches never even reaches the ground. True, this loss may not seem too significant, but Hoover (1953) found in a young loblolly pine plantation that on an annual basis, net rainfall to the soil will average about 86 percent of the rain in the open. Interception losses vary with crown densities and types of storms. In many stands a rain of 0.1 or 0.2-inch never even wets the litter, and a good portion of the annual precipitation is made up of such small storms.

The water that is not intercepted by foliage then hits the litter, and more

is returned to the air through evaporation before it can move through to the mineral soil. The water that trickles through the forest floor has another problem: can it move into the mineral soil? Usually some of it can, but if the rain is particularly intense, or if the surface is an eroded clay, the greater portion of it runs off immediately. Some of this surface runoff will sink into the soil but much of it ends up in streams, and if in the course of its travels it crosses bare soil it ends up carrying along mineral particles. These bits of mineral matter may settle out and plug the surface pores of the soil and thus make it more difficult for the entry of water into the soil, or they may stay in the water and end up by contributing to the sediment load of streams.

The water that gets into the soil now moves deeper. This may proceed smoothly until some sort of a restricting layer is encountered. Then the water moves through the soil horizontally, perhaps eventually soaking into the deeper layers or more probably ending up as surface water. In some soils these restricting layers may be several feet below the surface and in others they may be within an inch or so of the surface. If there is enough rain and the vegetation is dormant some water goes down and down until it is below the root zone. Such water may eventually become part of the ground water supply and is also lost to the vegetation, at least temporarily. So it becomes evident that only part of the rainfall we read about in the morning newspaper can be used by plants.

What are the soil properties which determine how much water will get into a soil and become available for plant growth? Essentially they are the infiltration rate (water intake at the surface), the percolation rate (movement of water in the soil), and the storage capacity (pore space which holds water). Soil porosity is the important characteristic of all three because not only do pores store the water, but they also serve as channels for movement into and through the soil.

Movement of Water Into the Soil

The movement of water into and through the soil, that is, infiltration and percolation, are the hydrologic properties most easily altered by forest practices. This is especially true of infiltration, a process primarily concerned with the surface half inch of soil. At this point it might be advisable to say something about the organic layers on top of the mineral soil. They are characteristic of forest soils and function as a screen and absorb most of the kinetic energy in rain drops. When the screen is removed, the soil itself must do the absorbing and in so doing is drastically changed. Rain drops falling on mineral soil detach particles and this suspended material then settles out and plug the surface of the soil.

For the mineral soil itself, texture is one of the soil properties which influences the intake of water. In general, the sandier the texture, the more rapid the movement of water will be. And for a given texture, an increase in organic matter will produce higher intake rates because it tends to loosen the soil. Conversely, any practice which either pushes mineral soil particles closer together (compaction by vehicles or man), reduces the organic matter content (exposure of mineral soil or intense burning), plugs the pores of the surface soil (muddy water moving across surface), or changes the surface from a coarse to a fine texture (erosion or artificial removal of topsoil), is going to reduce the infiltration rate. Lull (1959), discussing compaction, states, "whenever you put a foot down on forest or range land, you are—to a degree—compacting the soil. The hooves of cattle, the wheels of a vehicle, the weight of a dragged log; all these can compact the soil too. Soil compaction is a common and universal process." For the purposes of soil and water conservation, compaction is usually harmful because it reduces the pore space. Johnson (1952) found in western North Carolina that grazing appreciably affected total porosity of the soil. In the most heavily grazed type, cove-hardwood, total porosity in the surface 2-inch depth was reduced 43 percent; in the more lightly grazed oak-hickory type, 15 percent; and in the pine oak ridge type, 6 percent. Comparable values were found for the reduction in porosity at the 2- to 4-inch depth. These changes occurred over an 8-year period during which the cattle were on the area only during the summer months.

Anything influencing the infiltration rate will also affect the downward movement of water near the surface. And there are other things, such as restrictive layers, which may alter or intercept the downward movement of water. In the coastal plain region these may consist of hardpan layers, and in the Piedmont they may be the tough clay just beneath the plow layers. For example, Hoover (1950) noted that in an old field profile, the rate of downward movement of water near the soil surface was about 30 inches per hour, whereas at a depth of 8 inches, in the clay just beneath the sandy surface soil, it was reduced to 0.03 inches per hour. Quite often the percolation rate at still deeper depths will become greater, but this is of little value if there is a "bottleneck" holding the water back. One possible solution to a problem like this would be deep plowing of old field sites before they are planted to trees.

Water Storage

Assuming water gets into the soil, the other hydrologic property of interest is the storage of this water. There are two categories of storage:

detention, which occurs in the larger non-capillary pores; and the retention, that which takes place in the capillary pores. Detention water moves from the profile in a day or so but retention water is retained and available for plant growth.

Detention water, also referred to as subsurface flow, moves from the site so rapidly that plants don't have an opportunity to utilize it. Everyone has seen water seeping from a road cut just after a heavy rain, or water surfacing on sloping land to form small rivulets. This is detention water. Although it may not be of value to plants, it is important in reducing erosion and regulating the flow of water to streams. If this water is held for only a day it is useful in reducing the peak flow of streams. And water moving horizontally through the profile is not carrying mineral particles which settle out and plug the surface pores of the soil. A porous soil, which is loose and friable and has a low bulk density, is best for maximum detention storage.

Retention water, which is held in the capillary pores against the force of gravity, is not all available for plant growth. Some of it is held so tightly that plants cannot extract it for their use. This tightly held water is referred to as unavailable water and is held below the wilting point. The amount of water in the soil when plants begin to wilt varies with texture. For a sandy soil it may be one or two percent, whereas for some slack-water clays in the Delta region it may be as much as 30 percent by volume.

Retention storage is affected by texture. Lassen *et al.* (1952) point this out in a table which shows that fine sand has a retention storage capacity of 0.5 inches in depth of water per foot of soil. And for a clay this capacity is 4.5 inches. Organic matter increases storage by adding to the surface area in the soil.

Use of water by vegetation also produces space in the soil for the storage of subsequent rains. Throughout the South most of the soils are recharged during the winter months and the soil profile is usually at field capacity by the beginning of the growing season. Then evapotranspiration processes begin to remove water from the soil. During the growing season, moisture is continually pumped from the soil by vegetation and when the autumn rains begin there is considerable space in the soil for the storage of this water.

Discussion

The ideal forest soil, in a hydrologic sense, will take in and store large quantities of water. Such conditions are usually encountered in a virgin soil. Here can be found a good protective cover of organic debris on the

surface, an organically enriched surface soil which is very porous, and a gradual transition from one horizon to the next as one goes deeper into the profile. Because most of our present forest lands have been affected by man in the past, we seldom find these ideal conditions.

In the mountains there has been considerable erosion in the past. Many of the soils in this region are inherently thin, and this loss of soil greatly reduces the storage space for water. Erosion has been just as severe, or more so, in the southeastern Piedmont region. Practically all of this area has been under the plow from one to several times and often up to 2 feet of soil material has washed away. Now most of the old field sites are heavy clay soils with a layer of sand on the surface, a remnant of plowing in the past. On some areas the situation is worse in that no sandy surface soil is present.

In the sandhills the big problem from the hydrologic standpoint is the storage factor. Here are found deep layers of sand which have a very low retention storage capacity in the zone where roots grow. Water can readily enter these soils and it keeps moving right on through the profile. Any practice which will increase the quantity of finer mineral material, or add organic matter to the soil will improve storage conditions.

In the coastal plain it is often either a question of having not enough water or too much. Lack of water may be due to tight impervious clays near the surface, hardpan layers, or excessively drained sands. Typical areas with too much water are the "pine oak flats" in south Arkansas. These are flat, nearly bowl-shaped areas of compact silty clay soil a few acres to 60 acres in size, which dot the flatwoods pine area. Movement of water into these soils is extremely slow and often water stands on the surface for weeks after heavy spring rains. With ditches to remove only surface water, however, these sites are perfectly tolerable for pine. This is strictly a perched water table condition and not really wet lands sub-surface water like the low flatwoods of the lower coastal plains.

The loessial areas of the mid-south constitute another problem area. Such soils have high bulk densities at the surface and the infiltration and percolation rates are very slow. As a result, high erosion rates and rapid runoff are prevalent.

It is possible to maintain and/or restore desirable hydrologic properties to soil by following good forest practices. Of these, one of the most important is maintaining a layer of organic matter on the soil surface at all times. Practices which either bare or compact the soil should be held to a minimum. And any silvicultural treatment which will add organic matter to the soil should be adhered to. This may consist of growing cover crops on some sites before they are planted and favoring hardwood species with rapidly decomposing litter on others.

It is apparent that the properties of the soil profile essential to water movement and storage may be defined largely in terms of soil pores: their volume, size, shape, and continuity. However, it is likewise apparent that many other properties of the soil help determine just what the pore space will be like. For example, structure, texture, organic matter content, and any other properties, including chemical ones, which have some influence on plant growth, are related to pore space.

When working with forest soils, whether we are trying to determine hydrologic properties or estimating site quality, we must not be afraid to do a little digging. Sometimes it may be easy to judge the hydrologic properties on first sight. For example, we know pretty well what to expect from barren clay areas or areas on which water stands for weeks at a time. Under other conditions this is not always so simple. Observations of the vegetation on a site will not necessarily give the answer, because what is growing on the land will not clearly define the bulk density or porosity of the soil. Severity of past land use often determines whether the texture at the surface may be sand or clay. The length of time the soil has been supporting forest vegetation is going to have an effect on the properties of the soil. And the formation of the soil, whether it was formed from materials in place (residual), from windblown deposits (loessial), from materials carried by water (alluvial), or from material which just slid into place under the force of gravity (colluvial), is going to influence properties and reaction to treatments.

Water is one of our most important resources. The quantity and quality of water available for use by vegetation, industry, and the housewife depends to a great extent on the hydrologic properties of the forested lands of the South. As foresters or land managers we should attempt to keep the hydrologic properties of forest soils in an optimum condition.

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SOIL MOISTURE UTILIZATION
BY SOUTHERN FORESTS

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Tremendous quantities of water move through forest vegetation from the soil to the atmosphere. In the South, where the growing season is characterized by frequent long, hot days, it is not extravagant to estimate that a million gallons of water per year may be utilized by one acre of trees. Measurements have shown that an individual sawlog-size pine can remove up to 100 gallons from moist soil during the midday hours of a single hot summer day.

Of course, the great bulk of water absorbed from the ground is not retained by the trees in the manufacture of food or the formation of wood. It is transpired through the leaves into the atmosphere. The tree can thus be thought of as a kind of wick through which water is drawn by the energy of atmospheric radiation. A few molecules of water are shunted off en route to be used in tree growth processes.

Basically, the story is simple: When the soil is moist, the rate of forest water use is controlled by weather conditions and the nature of the forest vegetation. On cool, cloudy days much less water is transpired than on hot, clear days. Where the forest cover is sparse, much less water is transpired than where the cover is dense. However, after the soil has become dry the rate of water use under all conditions of weather and forest cover is very slow, simply because there is no available water left in the ground.

Source of Water

In the upland pine-hardwood forests of the South, the total water available to tree roots usually is only that held in storage by the soil particles themselves. Additional sources, such as lateral underground seepage or shallow water tables, are generally absent. The amount of stored water varies with soil texture and structure, with thickness of different soil horizons, and with other soil characteristics.

When rain has wet the soil for the entire depth of the root zone, and

after excess water has drained away, the quantity of available water under a forest stand may vary on different soils from the equivalent of only about 5 inches of rainfall to as much as 15 inches.

Evapotranspiration occurs at its maximum rate when the soil is at maximum storage capacity. At this level, water is held only loosely by the soil, and is easily removed. As the soil is depleted of moisture, the remaining water is held ever more tightly by individual soil particles, and the rate of evapotranspiration decreases proportionately (Ashcraft and Taylor, 1953; West and Perkman, 1953). As the soil approaches wilting point, during long periods without rain, actual water utilization becomes negligible. With each rainfall, the rate of evapotranspiration picks up immediately.

Soil water is withdrawn from the zones where it is most readily available. A dry soil when partially wet by a summer thunderstorm will be depleted rapidly from the moist zone at the soil surface, while practically no water will be removed from the dryer layers below the wetted front. When root distribution is uniform in deeper, well-aerated soil horizons, water may be withdrawn uniformly from all depths, as was the case in a young pine plantation studied by Hoover, *et al.* (1953). Conversely, where effective root depth is restricted by shallow soil or poor aeration, most of the water is supplied from the surface layers (Zahner, 1955).

Seasonal Aspects of Water Use

In the South the distribution of rainfall, which replenishes soil moisture storage, does not usually coincide with periods of high and low evapotranspiration. Forest water use is very low during winter months, with the result that excessive rainfall saturates the soil and often causes logging difficulties. During the summer, rainfall normally does not keep pace with the rapid water losses, and forest growth is consequently limited by inadequate moisture.

Carlson, Reinhart, and Horton (1956) found the rate of water depletion in Mississippi to be much greater during the summer than during the spring or fall, and greater during the spring or fall than during the winter. Rates of water loss up to 0.50-inch per day were reported by Broadfoot (1958) from Mississippi forests in mid-summer.

If soil were maintained constantly moist, either through excessive natural rainfall or controlled irrigation, water use by southern forests would probably average one inch per month during the winter, three inches per month during the spring and fall, and as much as eight inches per month during the summer (Zahner, 1956). Rates of maximum evapotranspiration have been estimated from various empirical formulae for

different seasons of the year (e.g., Thornthwaite, 1948), and these usually range from 0.01-inch per day for the winter season to about 0.18-inch per day for the summer in the South. Actual measured rates of maximum soil moisture loss have been found to be higher than that obtained by formulae for the summer period, averaging about 0.25-inch per day throughout the South (in Texas and Mississippi, unpublished data of Southern Forest Experiment Station; in South Carolina, Metz and Douglass, 1959; in Arkansas, Zahner, 1955).

Effects of Forest Management

There is little that can be done to increase the total storage of available water on a given forest site. As discussed above, storage is primarily a function of the soil profile, which under forested conditions can be altered only slightly by management and then only over a long period of time.

The forester has a great influence on the *rate* that water is used, however, during periods when the soil is depleting from moist to dry. He can regulate the transpiring effectiveness of the crown canopy and the distribution of roots in the soil. By controlling the size, spacing, and number of stems of various species, the forester controls soil moisture utilization.

Area-wide evapotranspiration is largely independent of the specific character of a forest cover which is completely occupying a site as long as the forest remains undisturbed and in equilibrium with its site. In South Carolina, for example, Metz and Douglass (1959) report that three different forest types—a pine-hardwood, a pole-sized pine, and a young pine plantation—all depleted the soil of water at the same rate. In Arkansas, stands of pure pine were found to use water at the same rate over the same period of time as stands of pure hardwood (Zahner, 1955). All-aged and even-aged stands have also been shown to deplete soil moisture at the same rates (Moyle and Zahner, 1954).

Forest management practices, which harvest commercial stems or deaden culls, alter evapotranspiration by removing crown area and releasing soil space. After such disturbance, transpiration may be less during periods of wet weather and greater during periods of dry weather, as will be evident from the examples below.

(1) An extreme forest disturbance, such as clear-cutting or a seed-tree harvest cut, results in so little occupancy by residual vegetation that water loss is reduced to a small fraction of that of the undisturbed stand. For at least the first season after such treatment, most of the moisture stored in the ground remains there, because its avenue of escape has

been cut. Water loss from a completely deadened cull-hardwood stand in Arkansas was only one-fourth that of the non-treated stand (Moyle and Zahner, 1954). At the end of even the driest summer, the soil remains moist under these conditions, implying that reproduction and lesser vegetation will flourish.

(2) Less severe disturbances, such as improvement cuts, pulpwood thinnings, and scattered cull-tree removal, also have their effect on soil moisture utilization. For example, the rate of soil moisture loss in a young pine plantation was found to be inversely proportional to the degree of thinning (Zahner and Whitmore, 1959). Moderate thinning reduced water loss to about three-fourths that of no thinning, while heavy thinning reduced loss to half that of the unthinned.

The lighter the disturbance, the more quickly will the site be completely reoccupied by residual stems and will water loss return to its maximum rate. The practical implication, of course, is that thinnings should be heavy enough to reduce water loss for the entire interval between thinnings, so that maximum soil-moisture depletion occurs only prior to each subsequent thinning.

(3) Disturbances resulting from prescribed burns and other forms of understory brush removal also alter the rate of water use. A chemical treatment which eradicated hardwood understories in fully stocked pine stands significantly decreased rates of water loss in Arkansas (Zahner, 1958). Such treatment may only temporarily affect depletion, for the pine roots alone might eventually occupy all the soil space formerly shared by pine and hardwood roots. Under management, however, a stand will be periodically thinned, thus releasing additional soil space. If hardwood brush is present, it will respond vigorously, increasing its competitive role. If hardwoods are absent, the freed soil space will gradually be utilized by the pine left after thinning.

Repeated control burning, which successfully kills root stocks, should have essentially the same effect on slowing soil moisture loss as does the chemically-treated brush control measure discussed above. However, single fires, or any cutting of hardwood stems without killing rootstocks, has a quite different effect on water utilization. When crowns are killed or cut, only the transpiring end of the plants is removed, for the absorbing end—the root system—is fully developed. Water losses are only briefly reduced, soon reaching a maximum rate again after new sprouts develop.

A Hypothetical Example

To summarize forest soil moisture utilization in the South, let us briefly trace the soil water regime in a fully-stocked young stand of pine. During

the winter months the ground is moist, and only the short, cool days restrict evapotranspiration, which is proceeding at a slow rate, perhaps 0.02-inch per day. As the days become longer and warmer, and as new spring growth increases the crown area, water loss increases five-fold during the spring to probably 0.10-inch per day. Spring rainfall currently replenishes the soil of this loss, so that in early June the soil may still be moist. The rate of water loss continues to increase with hot weather, to perhaps 0.25-inch per day, and now current rainfall can no longer maintain moist soil. The soil dries slowly to a fraction of its available storage, and the rate of water use decreases as soil moisture decreases. In five weeks water loss might be 0.10-inch per day, and in eight or ten weeks might be 0.02-inch per day. In mid-summer, therefore, the rate of actual water loss can be as low as in mid-winter, but from different causes.

Now let us take this same pine stand through the same seasons, but after it has been thinned so that about one-half of the crown and root area is removed. During the winter and spring months, water loss will be similar to that in the undisturbed stand, 0.02-inch per day and 0.10-inch per day respectively. However, by early June the maximum rate may be only 0.15-inch per day, little over half that of the unthinned stand. After five weeks of hot weather, the rate is still 0.15-inch per day, and after eight or ten weeks the rate in the thinned stand might still be 0.10-inch per day, thus far surpassing that in the undisturbed stand. Roots will have been growing into moist, unoccupied soil, and current summer rainfall will have more nearly replenished the needed supply. Therefore, while the thinned stand transpires less than the unthinned during wet weather, the situation is reversed during dry weather simply because the thinned stand still has a moisture supply and the other does not.

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THE SOIL CONSERVATION APPROACH
TO SOIL-WOODLAND INTERPRETATIONS

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Soil interpretations are an important part of the Cooperative Soil Survey now under way throughout the country. They include a systematic assemblage and organization of knowledge about each different kind of soil that is described and delineated on the soil map. We develop them for specific objectives such as production of ordinary cultivated field crops, irrigated crops, range crops, wood crops, and for engineering purposes, wildlife uses, etc. Soil interpretations for the production of wood crops is the subject of this discussion.

If we have enough information about soils and their influence on tree growth and management we can classify our knowledge into "woodland items of growth and management" that are correlated with soils. Some of these items are well recognized. Correlations are being developed between these woodland items and soil mapping units. They are the basis of soil interpretations for wood crop production being developed by the Soil Conservation Service.

The woodland items of growth and management for which soil interpretations are being developed include: Potential soil productivity, seedling mortality, plant competition, equipment limitations, erosion hazard, windthrow hazard, hazards from forest pests and diseases, special woodland products, species priority. All items may not apply in every locality or for every soil. Likewise other important relationships between soils and wood crop culture may not be included by these examples.

In developing soil interpretations each mapping unit in a survey area is "rated" for each soil-correlated woodland item of growth and management. Ratings are usually qualitative and are designated by numbers such as 1, 2, or 3, which signify a relative degree of problem, hazard, or limitation, such as "slight," "moderate," or "severe." Criteria are first developed for soil ratings in each of the woodland items or subdivisions of them. The criteria are designed so that ratings will characterize each mapping unit and guide woodland owners into specific kinds of practices related to their soil resources. For instance, a rating of "slight" for windthrow hazard on one soil mapping unit would indicate

that cuttings could be made without reference to any hazards of loss of residual stand due to windthrow. On the other hand, if a soil mapping unit is rated "severe" in this item the woodland owner may wish to choose one of several alternatives in his cutting operations to prevent possible financial loss due to windthrow.

Potential soil productivity is usually rated by determining the average site index for tree species or forest types (wood crops), on each known soil. These ratings, translated into quantitative predictions of potential yield, form a good economic basis for grouping soils to simplify and apply this kind of knowledge about them.

Ratings of soil mapping units for items of woodland growth and management are based on published research, work in progress, field observations, and experience and judgment of those in an area who are most familiar with the soils and with woodland conservation. Site index-soil correlations are becoming more and more available. Many of these are based on correlations between site index and one or more single soil characteristics. Interpolation of results into soil mapping units is necessary before the information can be used most conveniently by woodland owners to guide their operations.

Basic research relating other woodland items to soils is very scarce or lacking. This indicates some specific research needs in forest soils.

The Soil Conservation Service has found it desirable to group soils with similar capabilities, hazards, and limitations to simplify the presentation of information about them. These are called woodland suitability groupings, when developed for woodland purposes. With adequate soil surveys and simplified interpretations, such as these groupings, woodland owners are able to use soil information as a basic tool in managing their wood-producing enterprises.

Woodland suitability groupings are based on the ratings of individual soil mapping units for each item of woodland growth and management selected as being important in an area. The ratings, together with complete knowledge of soil characteristics, allow a listing of the soils by groups so that the greatest amount of uniformity exists and important items of woodland growth and management are correlated. This listing needs to be accompanied by some narrative that explains specific soil interpretations, and to relate soil information by suitability groups to alternative choices of wood crops or to practices that need to be considered by the woodland owner.

Woodland suitability groupings and relevant explanations are developed usually on a natural or problem-area basis. They make up an important part of the information used by technicians in working with

cooperators of soil conservation districts. Such interpretive information is being prepared as a part of the standard soil surveys. They will appear in future published soil survey reports.

FOREST SITE CLASSIFICATION IN
THE SOUTHEAST: AN EVALUATION

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The history of forestry in Europe shows us that as forest management becomes more intensive, site classification also becomes more intensive. At first there is only the crudest of *productivity* grading of forest sites, based on obvious characteristics of the forest and of the physical environment. There follows a stage of *quantitative* productivity grading, of ever increasing refinement. The most useful measure of productivity has traditionally been the height growth of dominant trees, a measure which generally must be applied separately for different tree species. Eventually, economic pressure for maximum efficiency in forest management focuses attention on attributes of forest sites other than productivity for one or two tree species, and there begins an advanced stage of *total site* classification.

In the Southeast, we can scarcely be thought of as being beyond the stage of quantitative grading of forest site productivity. Where suitable stands exist, we can assess productivity through measuring average dominant tree heights. For each of the major southern pine species we can adjust these heights to an index age by means of site index curves and obtain site indexes. We have refined the accuracy of these curves to a very limited extent. In order to be able to assess productivity where suitable stands for tree measurements are not available, we have on the one hand correlated site index with soil and other physical site properties in a series of statistical regression studies, and on the other hand we have related site indexes directly to conventional soil types.

It is the purpose of this paper to render an evaluation of some of these productivity classification techniques in the Southeast. A further purpose is to take a look at our needs and opportunities in this region for progressing into the field of total site classification.

Site Index

Errors inherent in conventional site index curves are discussed by Spurr (1952), by Carmean (1956), and by others, and will not be discussed here in detail. In the Southeast, Coile and Schumacher (1953) and Cobb (1957) have demonstrated a correction technique that will tend to eliminate mass bias in the shapes of these curves, but the unfounded assumption that all sites have the same shape of height-age curves is still retained after the correction. That sites can have different shapes of height-age curves, even when of the same site index, has been demonstrated in the Northwest (Carmean, 1956) and can be reasonably hypothesized for most of the major tree species in the Southeast. We must conclude that we simply do not have any truly reliable site index curves for general use in this region. However, they cannot cause any significant error if we use them only with height measurements taken from stands near the index age. In the writer's opinion, measurements from stands of ages 40 to 65 should yield quite precise estimates of site index; measurements from stands under age 25 should generally be considered unreliable.

It seems desirable to evaluate the soil-site index regression technique from the standpoint of statistical validity. The conditions for validity of regression analysis are best expressed in terms of the model,

$$Y = \alpha + \beta x + \epsilon$$

(Snedecor, 1956). Y is any value of the dependent variable (e.g., a site index or the logarithm of a site index), and x is the deviation, $X - x$, of the independent variable from its mean. α and β are parameters, α being the mean value of the population of Y, and β defining the slope of the regression line in terms of change in Y per unit change in x. ϵ is the variable part of Y that is not defined by the regression line, $\alpha + \beta x$. In terms of this model, the conditions for validity of regression analysis are that:

(a) the regression be strictly linear; and
(b) the ϵ's be normally distributed about the regression line in a random manner and be independent of the x values (Wold and Juréen, 1953; Snedecor, 1956).

From the model is drawn the linear regression equation

$$Y = a + bx + e,[2]$$

Wherein a and b are estimates of α and β respectively, and e contains ϵ plus

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[2]In the familiar equation $\hat{Y} = a + bx$, $\hat{Y}$ is an estimate of Y that differs from Y to the extent of the value e. In other words, $\hat{Y} = Y - e$.

the errors made in making the estimates a and b. e can perhaps best be termed the "discrepancy" or the "statistical error term". For purposes of this discussion, the term bx can be looked upon as either a single term from a simple regression, or a composite term, made up of b_1x_1, b_2x_2, etc., from a multiple regression. The conditions of validity are the same for this equation as for the model, except, of course, that it is the e's instead of the ϵ's that must be randomly distributed and independent.

In soil-site index regression studies, linearity (condition a), if not already present, is achieved by means of mathematically transforming the curvilinear regression to a linear form. The condition of random and independent discrepancies (condition b) is not met, since this can be achieved completely only through the replication and randomization procedures of the careful experimental design (Wold and Juréen, 1953). The soil-site index regression studies have not employed experimental designs, of course, but have depended upon simple field surveys for their data.

The practical implications of the failure to obtain independent discrepancies can best be visualized by considering the results of two hypothetical soil-site regression studies, one covering a large, ecologically variable geographical area and the other covering a small, ecologically simple area.

Let us say that about a fifth of the large, complex area has rough topography and that four-fifths has gentle topography. For the sake of simplicity, let us assume that the rough country is in a single sector. The soil-site investigator, after taking data from the usual 100 to 200 plots, compiles a large list of possible independent variables. Following the accepted procedure in such analyses, he finds that, with the inclusion of the two or three most potent variables in his prediction equation, the addition of any other variables will not reduce the residual deviations significantly and will raise the standard error of the estimate for his regression. He therefore includes only the two or three most potent variables in his final predicting equation. Let us say that in this case there are two significant variables, depth to subsoil and moisture equivalent of the subsoil. Slope position, slope gradient, the interaction of these two, and the interaction of m.e. of the subsoil with slope position were among the many variables that were not significant. The investigator may feel surprised that slope position could in no way give further significant reduction to deviations. He may conclude that this factor is entirely reflected by depth to the subsoil, or he may go into the rough segment of his study area and check-measure the site indexes of stands occupying different topographic positions where the topsoil has been completely lost by past erosion and where m.e.'s of the subsoil are approximately equal. If he does the latter, he will most certainly find the eroded

lower slopes and coves to be superior in site index to the eroded mid-slopes and upper slopes, contrary to the results forecast by his predicting equation. Generalizing on his experience, he will be forced to conclusions of the following nature:

1. In this large, complex study area, meaningful variables other than the statistically significant ones exist; but these have failed to show significance because of one or more of the following reasons:
    a. They are associated with local conditions (e.g., the rough sector in the hypothetical case) and thus have been inadequately sampled.
    b. They are well distributed but occur so infrequently as to have been inadequately sampled.
    c. They are correlated with the significant variables to an extent that much of their effect has been removed by these. Sampling has been inadequate to bring out that part of their effect not so removed.
    d. Some may not have been included in the original list of variables to be tested. In a large and complex study area, it is difficult to conceive of and to formulate all the possible independent variables.
2. Whatever the reason for their existence, all of these meaningful but statistically non-significant variables must be included in e, the statistical error term of the regression equation, along with the randomly distributed observational errors. Many of these excluded variables are obviously related to the x and Y values of the linear regression equation. Thus the condition of random and independent distribution of the discrepancies is violated.

What does this violation do to the effectiveness of the prediction equation already developed? Cochran and Cox (1957) state that dependence in statistical errors "might completely vitiate tests of significance." Wold and Juréen (1953) emphasize the damage to standard errors of the regression coefficients. They state that these, as calculated, will be in error by undeterminable amounts, and they imply that the calculated standard errors will be too low. This would mean that confidence limits, as calculated for any site index value other than the mean value for the study area, would be unreliable. An arbitrary example of this situation is pictured graphically for a simple linear regression in Figure 2.

The standard error of the estimate, which sets the confidence limits at the mean site index value of the study area, will be reliable on the average basis. However, it will be too low for some local areas and for some conditions and too high for other areas and conditions. In the rough, hilly sector of our hypothetical large study area for instance, the calculated
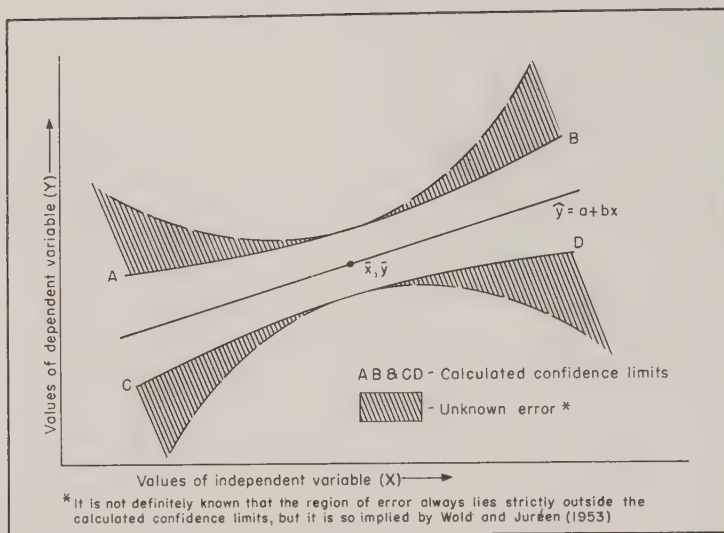
Figure 2. Effect of dependency in the discrepancy factor upon the confidence limits in a linear regression.

standard error of the estimate will be too low; it may, for example, be represented as 10 percent of the mean site index value when 20 percent or 30 percent might actually be more nearly true of the local situation. A separate sampling and regression study for the rough, hilly sector would, of course, have yielded a far more reliable standard error of estimate, as well as a more reliable estimate. Separate samplings and regression studies for the rough sector and the gentle sector would have yielded standard errors of the estimate with a mean value lower than the standard error of the estimate from the over-all study.

If a large number of site index predictions are made from the equation developed for the large, complex area, the values will average out true. But this is not really saying very much since the same can be said for using the mean site index as a predictor. The equation will, of course, be a more nearly precise predictor than the mean, but there is no way of answering the question, *"How much* more precise?" In addition, there is a possibility of distinctly biased estimates under certain special conditions. Imagine the results, for instance, of using the over-all prediction equation for evaluating only the best sites in the rough, hilly sector of our hypo-thetical large area. Since most of the best sites would be on lower slopes and in coves, the site index estimations would be rather consistently low. One is forced to the conclusion that such an equation can be used as a reliable prediction tool only by someone who can accurately adjust the predicted values at the right times and places. Such a person would have

to be thoroughly familiar with both the regression study involved and the various sites in the area sampled. The only person who would seem to fit this description would be the investigator who made the regression study.

If our soil-site index investigator conducts a regression study on a small, ecologically simple area, he takes his plot data and then compiles a much smaller list of possible independent variables than he did for the large, complex area. He again finds that only two or three of the most potent variables can be used in a predicting equation. (Note, however, that the ratio of the number of significant variables to the total number of variables has risen.) Again he may be surprised at some of the variables that prove non-significant, but this time he has a much more equable sampling upon which to rely because of the more uniform nature of his study area. His study is not a controlled experiment, but it is about as close an approach to a controlled experiment as he can achieve under the circumstances. He knows that while error is still theoretically present in his standard errors of regression coefficients, this error should be much nearer a minimum than in the case of the large, complex study area.

A word should be said at this point about using age as an independent variable and height instead of site index as the dependent variable. This practice may be necessary in some site regression studies because of the scarcity of stands near the index age. Also, the prediction of heights at ages other than the index age may be an important objective of the investigator. It should be realized, however, that the use of stand age as a variable will most likely aggravate the validity problem which we have been discussing. It seems quite likely that age may be correlated with some important environmental variables, yet age interaction terms are seldom included in prediction equations that use age as a variable. Thus the amount of dependence in the statistical error term, e, in the linear regression equation will be increased. The inclusion of age as a variable also has the unfortunate effect of producing large multiple correlation coefficients, causing many to conclude incorrectly that a large proportion of variation in height has been accounted for by environmental factors.

Examination of the published soil-site index regression studies reveals that the investigators involved have apparently been learning by experience of these hazards in the regression technique. Earlier studies did cover large and ecologically complex areas, but later studies have been based upon smaller and more nearly uniform areas. In the latest published study in the Southeast, Zahner (1958) kept the study area relatively small, and made separate analyses for soils of different geologic origins and for soils of different zonality classes. He located his plots in stands 38 to 60 years old, and did not use age as an independent variable in his regressions. He felt enough confidence in his standard errors of regression coefficients to in-

clude them in his article, something rarely done in pervious reports of this kind. On the whole, it is felt that this report comes about as near as possible to developing, through use of the regression technique, a forest site productivity classification of general utility. There is no intent here to belittle the importance of the earlier studies. These ably demonstrate the application of an important new technique in forest soil science. However, most important new techniques in any field have "bugs" in them that can be eliminated only with the passage of time.

A great many foresters and other land technicians in the Southeast have for many years relied upon conventional soil types to furnish the basis for productivity mapping of forest land. The fact that vast areas of forest land have been mapped for soil types is tempting bait for this proposition. The technique is one of simply measuring and using a mean site index for each soil type. Allowances for climatic influences are made by assigning different site indexes to a given soil type by states or by portions of states.

The use of soil types in this way as guides to site index is often either inefficient, or technically inadequate, or both inefficient and technically inadequate. It may be inefficient in that whole groups of soil series or soil types within given localities may have equal site indexes (Spurr, 1952). It may be technically inadequate because of too much variation in productivity within single soil types where the topography is even slightly hilly (Wilde, 1958). Thus we find that the conventional soil types are both too specific and too general to serve as a ready-made system of forest site productivity classification. Their use in this way is possibly defensible only in certain areas of very gentle topography.

Given a representative scattering of stands which will provide site index measurements, the typical forester should be able to create his own local productivity classification. Many foresters undoubtedly do this; and, if their systems are thoughtfully devised, they will be hard to beat. The approach is one of organizing topography-soil profile classes under appropriate site index classes. In this, conventional soil type descriptions and maps can be very helpful. An example of a local classification of this kind for longleaf pine in the Little River State Forest and vicinity in Alabama (Hodgkins, 1956) is schematically presented in Figure 3. Note that five different soil types in the Citronelle formation are included in two out of the three site index classes, demonstrating both the inefficiency and the inadequacy of basing a classification on soil types alone.

Total Site

When one understands that a given site index for a given species may occur on *more* than one site, he has taken a long step toward understand-

ing the concepts of total site and total site classification. In Figure 3, for instance, site index 80 for longleaf pine is found on flat upland soils of the Citronelle formation, on lower slopes just above terraces, on inner terraces, and on slopes just above main branch bottoms. On the basis of site index, only one site class is involved. On the basis of total site, four site classes are involved.
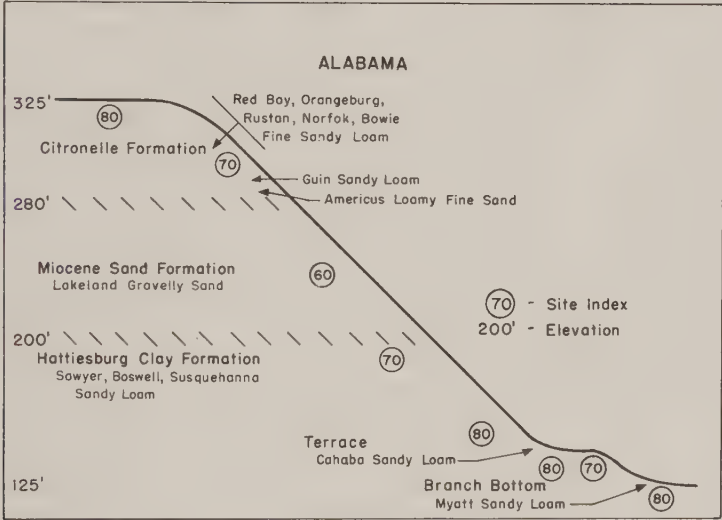
Figure 3.   Schematic diagram showing physiography and longleaf site indexes of
Little River State Forest, Alabama.

In total site classification, site index is relegated to the status of one of many attributes of the site, and is no longer the basis for classification. This does not constitute a de-emphasis of site index, but rather a recognition that other attributes of the site are also important. For instance, there is evidence that sawtimber rotations are not economically feasible on the flat upland site in Figure 3 because the shallow subsoil of this site causes restricted diameter growth after about age 50. There are many other differences among the four sites of site index 80. The use of total site classification implies that research on forest land and management of forest land will be done with due regard for *all* of the significant attributes of the various site classes. Thus total site classification becomes most fundamental to an advanced and intensive brand of forestry.

Much thought and discussion have been devoted to the subject of total site classification, and some very promising advances in technique have been developed and proved in the past thirty years. Consequently it seems worthwhile to review briefly the better known techniques, with an eye to-

ward possible application of some of them in the Southeast. Considering the rapidly improving economic environment in this region for intensive forestry, it seems likely that in the future we shall have to give much more thought to total site than we have in the past.

Total site can be classified on the basis of the vegetation which results from it, on the basis of the environmental factors which compose it, or on a combination basis.

Fundamental to the classification of sites by means of vegetation is the existence of species with "narrow ecological amplitudes," species that tolerate only very narrow ranges of environmental conditions. The principal criterion for the individual site class has been historically the presence (and absence) of these species (Cajander, 1926; Braun-Blanquet, 1921). "Narrow amplitude" species are usually lesser vegetation species rather than tree species, perhaps because the generally shallower root systems of the lesser vegetation species make them more sensitive than tree species to slight differences in site. Tree species, with their generally broader tolerances of differences in site, are often useful in defining broader classes of site that may each include several or many unit divisions defined by the lesser species (Köstler, 1949; Becking, 1957).

Species of narrow ecological amplitude can be used to characterize site directly, or they can be used to characterize the plant community which in turn characterizes the total site. Of the two approaches, the latter has had by far the greater amount of exploration and success. Unfortunately, because of the wide ecological amplitudes of a great many lesser plant species, most foresters find it difficult to grasp the universality of orderly plant societies and associations (Linteau, 1953), and thus the whole idea of characterizing site by means of the plant community seems rather unrealistic to them. This situation seems to be particularly true in the Southeast, where in most places species of wide amplitude far overshadow those of narrow amplitude.

In earlier vegetational classifications of site, it was thought, following the general lead of Cajander (1926), that the community-characterizing species should be dominant species in their particular strata of the forest. This idea yielded the rather precise forest site types that are now commonly accepted in much of northern Europe. As one progresses southward, however, the proportion of dominant species having narrow ecological amplitudes seems to decrease markedly. Probably for this reason, these earlier systems never made much headway in central Europe. Instead, under the general leadership of Braun-Blanquet, systems stressing fidelity and constance of species presence have had rather remarkable success (Becking, 1957; Major, 1957). In these systems, analysis of the *total* plant life is stressed. Character species are often, though not neces-

sarily, minor and obscure species. Communities, or forest site types, are identified through an inductive synthesis process applied to the data from a region-wide survey (Oosting, 1948).

In Canada and the United States, vegetational forest site classification has had a similar history to that of Europe, although considerably delayed. The Cajander approach has proven fruitful in Canada and in northeastern United States (Heimburger, 1934; Sisam, 1938; Spurr, 1952; Westveld, 1952; Wilde, 1958). Spurr (1952), noting that single characterizing species were not very reliable, devised for northeastern spruce and fir forests an "indicator spectrum" of characterizing species ranging from the poorest site indicators to the best site indicators. When the indicator spectrum is applied to a given site, a *group* of the species will emerge as predominant and will identify the site. Spurr's variation of the Cajander approach may be applicable under some conditions in the Southeast. The Braun-Blanquet approach, of which most American foresters are largely ignorant and which has had very little trial, seems to have given excellent results where tried, both in Canada (Linteau, 1953) and in the United States (Becking, 1956). By this approach the Douglas-fir type of western Oregon and Washington was successfully classified into 14 different site types, each a distinct ecological entity with a distinct productivity. The approach certainly deserves a real trial in such southeastern types as longleaf pine and bottomland hardwoods. As stated by Linteau (1953), successional stages should not hinder the successful development and application of the Braun-Blanquet approach, except in the case of recently bared lands.

When total site is classified on the basis of the environmental factors that compose it, emphasis is almost always placed on the physical factors of topography and soil that are known to be strongly related to moisture and drainage regimes. Coile (1938), who looked upon these physical factors as the truly fundamental and permanent features of site, proposed a list of the factors to be used in a classification scheme. No one, however, has apparently ever organized these factors or a similar list into a comprehensive classification system for the Southeast or for any part of the Southeast. An example of what such a system might look like is given by Gysel and Arend (1953) for oak sites in southern Michigan. All sites are first divided into three classes according to subsoil texture: fine, medium, and coarse. The further subdivision of the medium soils is shown in Table 1. This sort of classification can be referred to as a "natural" or a "pigeonhole" physical classification. "Site quality," in the last column of Table 1, is not a part of the classification system but is rather a major attribute of the various classes.

The significant independent variables resulting from soil-site index

TABLE 1. Site classification for upland oak sites in southern Michigan (Gysel and Arend, 1953).[1]

Site designation[2]	Texture of subsoil	Position of moist layer in substratum	General Topography	Position on slope	Site Quality
1 to 8	Fine	(8 sites in all, with site qualities "medium" to "very good")			
9	Medium	Low	Flat		Medium
10		Low	Rolling	Upper	Medium
11				Middle	Medium
12				Lower	Good
13				Bottom	Very Good
14		Low	Hilly	Upper	Poor
15				Middle	Medium
16				Lower	Good
17		High	Flat		Good
18		High	Rolling	Middle	Good
19 to 28	Coarse	(10 sites in all, with site qualities "very poor" to "good")			

[1] Developed from field observations and from trial data groupings.
[2] This column added to Gysel and Arend's original table.

TABLE 2. A possible total site classification for zonal upland soils in south Arkansas and north Louisiana.[1]

Site class	Slope	Texture of subsoil	Thickness of surface soil	Loblolly pine site index	Shortleaf pine site index
A	Gentle	Light	Shallow	73	69
B			Medium	82	76
C			Deep	74	72
D		Medium	Shallow	80	74
E			Medium	88	80
F			Deep	80	76
G		Heavy	Shallow	74	72
H			Medium	82	79
I			Deep	75	74
J	Steep	Light	Shallow	68	62
K			Medium	76	68
L			Deep	69	65
M		Medium	Shallow	74	67
N			Medium	82	72
O			Deep	74	69
P		Heavy	Shallow	68	63
Q			Medium	76	69
R			Deep	68	66

[1] Organized from Zahner's (1957) regression variables.

regression study are normally expressions of physical site factors and, as such, can be organized into total site classification systems. Taken from most of the existing published studies, however, such systems would be unsatisfactory because they would not contain certain important and useful classification factors. These factors are missing from the prediction equations for reasons previously discussed. Table 2 shows a total site classification devised from two of Zahner's (1957) regressions. Unfamiliar with the study area involved, the writer is in no position to appraise the adequacy or utility of this classification.

G. A. Hills (1952) of Canada has devised a somewhat unique system of classifying total site from physiographic factors. It differs from the "natural" or "pigeon-hole" system in that, for a particular "land type" within a given climatic region, physiographic sites must be based on nine subjectively-ranked moisture regimes and five permeability classes. Judging from a published classification given thirteen basic site types for a large area just north of Lake Superior (Bedell and MacLean, 1952), it will be difficult for a mapper to identify all of Hills' sites with precision because of vagueness and overlapping in some of the site-type descriptions. Such vagueness and overlapping are probably unavoidable in this system because of the difficulties inherent in precisely describing nine subjectively-ranked moisture regimes in the first place. A vegetational system for the same kind of area (Linteau, 1953) yielded seventeen precisely identifiable site types, requiring on the part of the user only that he be able to recognize fifteen species of lesser vegetation.

Combining the ideas of vegetational and of physical site typing would seem to be an obvious way of overcoming some of the major weaknesses of both approaches. Wilde (1958) gives what is basically a natural physical system based on morphological and genetic characteristics of soils, but he refines his ultimate physical classes by means of vegetational typing. Westveld (1952) gives an admirable demonstration of combining vegetational site typing, conventional soil type mapping, and climax forest typing for evaluating forest site quality in the Northeast. Köstler (1949) describes a composite system of forest site associations for southern Germany that draws upon the works of several authors who have used various vegetational and physical approaches. Brown (1954) describes the use of soil profile characters and natural vegetation as guides in choosing species for wasteland afforestation in the West European section of the North Temperate Zone. At the Eleventh Congress of the International Union of Forest Research Organizations (1954), the opinion was expressed in meeting by F. Hartmann that, where the primary forest had been modified, some types of sites could be satisfactorily identified only through the use of both floristic and pedologic indicators.

Conclusions

Those southeastern forest managers who are interested primarily in productivity classifications for specific tree species should not hesitate to use direct site index measurements where the rather narrow limitations for these can be met. Forest managers can often use site index measurements to establish their own local productivity classifications applicable to areas where direct site index cannot be obtained. When they make use of regression-type studies for this purpose, they should make certain that one of the two following conditions is complied with:

1. If the regression study area (or areas) is large and complex, the man who uses the prediction equation must be thoroughly familiar with both the regression study and the area to be typed.
2. The regression studies involved are for relatively uniform conditions of topography and soil formation.

For the purpose of improving future silvicultural practice, forest managers should begin thinking and acting now on terms of *total site* instead of site index.

Southeastern researchers in forest site classification should be dominated in their future thinking by the concept of total site. They should think in terms of the broadest possible classifications, for this will permit maximum utility. A single site classification system for the entire Southeast and for all commercial tree species therein is probably not practical, but what a wonderful boon it would be to all of us!

When devising new site classifications, researchers should make all possible use of the best techniques developed in the Southeast and in other parts of the world, but they should use these techniques strictly as tools and not allow *any* of them to dominate their thinking.

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SOIL-SITE STUDIES
OF SOUTHERN HARDWOODS [1]

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The rapid development of forest management in the South during the past two or three decades has marked an important milestone in American forestry. Much of this progress has been directed toward the southern pines with relatively little work on southern hardwoods. This situation is reflected in Coile's monograph (1952) on soil-site studies in which he reported on all work up to 1952. For the southern region, practically all such studies had been on six species, all of them pines.

A shift in emphasis appears to be taking place, however, with more effort being devoted to the research and management of southern hardwoods. This change is justified by available survey information. According to recent timber resource reports (U.S. Forest Service, 1958), about one-eighth of the commercial forest land in the nation is in bottomland-hardwood forest types in the eastern states. With a surprising consistency, Forest Survey reports for areas within the South indicate about 20 per cent of the forest acreage is occupied by such types.

The bottomland hardwoods of the South are an important forest resource both in acreage and volume. They grow on some of the most productive sites we have. Both common sense and sound forest management dictate that more attention be given to their appraisal and management.

Review of Previous Work

Relatively few soil-site studies have been made on bottomland hardwoods in the South. Putnam (1951) assigned a "comparative growth rate" to each species but made no attempt to quantitatively classify different sites for a given species.

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[1] A portion of this paper is condensed from a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Forestry in the School of Forestry of Duke University.

Nelson and Beaufait (1956) pointed out several difficulties involved in the application of conventional site index methods to hardwoods. Among these were the prevalence of uneven-aged stands and the occurrence of many stands that were too young, overcut, or otherwise abused. They presented preliminary data from studies made in the Georgia Piedmont indicating no significant difference between site indexes for yellow poplar (*Liriodendron tulipifera* L.) and sweetgum (*Liquidambar styraciflua* L.) on the sites encountered. It is interesting to note that they found both of these hardwoods outgrowing loblolly pine (*Pinus taeda* L.) on plots with site indexes above 90 feet for the pine.

In 1956, Beaufait reported on an intensive study of willow oak (*Quercus phellos* L.) site relationships. Eighty-three plots were examined throughout the South; 50 were within the Mississippi River Delta area, and 33 from non-Delta river-bottoms outside the Mississippi River system. He found that small topographic variations caused relatively large site index changes. Growth was best where surface drainage was good and became progressively poorer with the lower, more poorly-drained sites. Beaufait recognized the four following topographic sites: high ridge, low ridge, high flat, and low flat. Separate site index curves were prepared for each of these sites.

Detailed soil analyses for the willow oak plots indicated that a number of soil variables were significantly related to site index. For ease of application by practicing foresters, however, only those were retained which could be readily determined in the field or by public soil testing agencies. Thus, for Mississippi River willow oak, site index decreased as the percent clay in the 12-inch to 18-inch layer increased. For willow oak in the non-Delta plots, site index was related to the exchangeable potassium in the 0 to 6-inch layer. Site index increased slightly as exchangeable potassium increased from 50 to 100 pounds per acre. Above the 100-pound level, site index decreased rather sharply to the lowest indexes encountered, at 500 pounds exchangeable potassium per acre. Beaufait developed tables from which willow oak site index could be read if the necessary topographic and soils data were at hand.

The Delta Research Center is currently carrying on additional soil-site research for a number of bottomland species. Sweetgum is being most intensively studied but work is also being done on cherrybark oak (*Quercus falcata* var. *pagodaefolia* Ell.), cottonwood (*Populus deltoides* Bartr.), water oak (*Quercus nigra* L.), Nuttall oak (*Quercus nuttallii* Palmer), green ash (*Fraxinus pennsylvanica* Marsh.), and cow oak (*Quercus michauxii* Nutt.). The studies are designed to make it possible for the landowner to estimate site potential in one of three ways:

(1) from standard soil survey maps, if available;

(2) from a chemical and physical analysis of soil samples taken from the area; or

(3) from a field examination of the site and use of a practical key based on easily recognizable site characteristics.

Swamp Blackgum and Tupelogum Study[2]

The writer (1959) has reported on a study made in southeastern Georgia involving soil-site relationships of swamp blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), and tupelogum (*Nyssa aquatica* L.). The remainder of this paper will discuss some of the results of this study.

Physiographic Sites

Swamp blackgum and, to a lesser extent, tupelogum, grow on a wide variety of wet sites. At the outset, therefore, it was decided to define the common sites and classify study plots accordingly. It was hoped that site index differences could be related to these site classes making for easier application by field personnel. Five such "physiographic" sites were recognized as follows:

(1) Swamp: a broad alluvial basin or drainageway, arbitrarily at least 10 chains wide, which is usually situated between tidewater and upstream runs.

(2) Run: a relatively narrow alluvial floodplain varying in width from less than one chain up to the arbitrary 10 chains. Other local names for run include "strand," "branch," or "streamer." Runs are usually the least wet of the gum sites.

(3) Pond: a relatively small saucer-like depression with essentially no surface drainage.

(4) Bay: a large depressed area with very slow surface drainage and highly organic soil. Bays encountered in the study were similar to the famous elliptical bays or pocosins of the Carolinas.

(5) Riverbottom: a general term applied to any gum site found in the major through-flowing rivers. In this study, plots were taken in the Altamaha, Ocmulgee, and Satilla riverbottoms.

Plot Location and Layout

Ninety study plots were measured in eight counties in the Lower Coastal Plain of southeastern Georgia. Seventy-three of these plots were classified as swamp blackgum, nine as tupelogum, and eight were mixed plots which provided mensurational data for both species. Swamp blackgum occurred on all five physiographic sites but most plots were taken in swamps, runs, and ponds. All tupelogum plots were in swamp sites except two in riverbottom sloughs.

Study plots were located in well-stocked, apparently even-aged stands in which the study species made up more than half the total number of stems. Stands selected were at least 20 years of age and with no evidence of cutting during the preceding 10 years.

Variable-radii circular plots with a common center were used to obtain stand and stocking data on saw timber, pulpwood, and sapling-size trees. Reproduction data were obtained from four milacre plots on each study area. Detailed mensurational data were tallied on eight selected trees, six in the dominant or co-dominant crown class, one in the intermediate class, and one in the suppressed crown class. The eight increment cores were placed in drinking straws for later analysis in the laboratory.

Soils information was obtained at four points on each plot by digging or augering to a six-foot depth and recording recognizable differences in the soil layers. No "normal" profiles were encountered since these wet-site soils were all intrazonal or azonal. Composite soil samples were taken from the different layers. In all cases, samples were collected from the "surface soil" and the "least permeable horizon" for later analysis. Soil samples were taken on 60 of the 90 plots.

Increment Core Analysis

Determination of total tree age was one of the major problems encountered throughout this study. Wood of both swamp blackgum and tupelogum is cream colored, diffuse-porous with small pores, and with very indistinct annual rings. Ordinary field methods of reading increment cores were not satisfactory. The problem was finally resolved with the fabrication of a special core holder designed by Reineke (1941) over 15 years ago. The holder is made of thin steel arms which grip the core with a firm vise-like action. Thus, the upper and lower portions of the core can be sliced off producing a clear transverse section for microscopic viewing. An additional aid was the use of a methylene blue-malachite green stain[3] which increased differentiation of growth rings.

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[3]This stain was suggested by M. Y. Pillow of the U. S. Forest Products Laboratory.
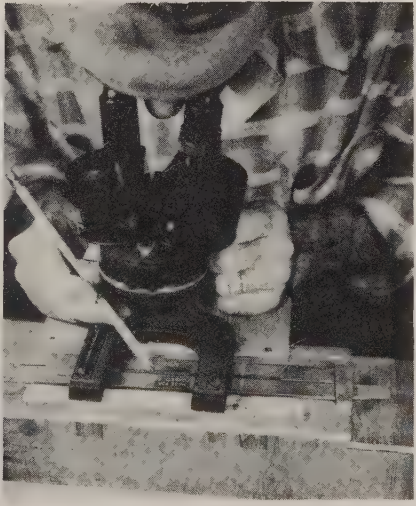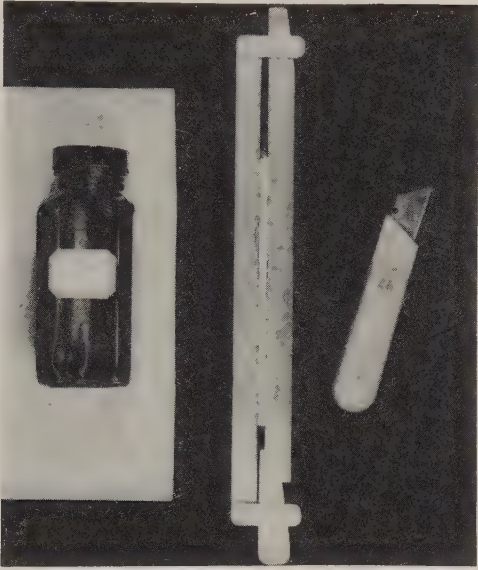
Figure 4. Core analysis methods and equipment. Top—stain, Reineke coreholder, and knife; left—slicing a core; right—examining a core with binocular microscope and lightbox.

After slicing, staining, and drying, the cores were repositioned in the core holder and the core centered over a cheesebox-size light box. Transmitted light was found to be superior to reflected light for careful ring counting. Finally, a binocular microscope was used at 10X to 23X magnification to examine and count the rings.

Soil Analyses

Laboratory soil analyses included mechanical analysis, loss on ignition, pH, and antacid buffering capacity. Mechanical analyses were made on least permeable horizons using the hydrometer method of Bouyoucos (1936). Loss on ignition was determined for surface soils by ignition in a muffle furnace. This value was used as an indication of organic matter content. The pH measurement was made electrometrically on both surface soil and least permeable horizon for each plot. Antacid buffering capacity was determined for surface soils only using a method similar to one described by Coile (1940).

Height-Age and Site Index Relations

Height-age regressions were calculated for each species using the type of equation developed by Schumacher (1939). The equations and curves are shown graphically in Figure 5. The data obtained in this study indicate a more rapid height growth for tupelogum than for swamp blackgum.
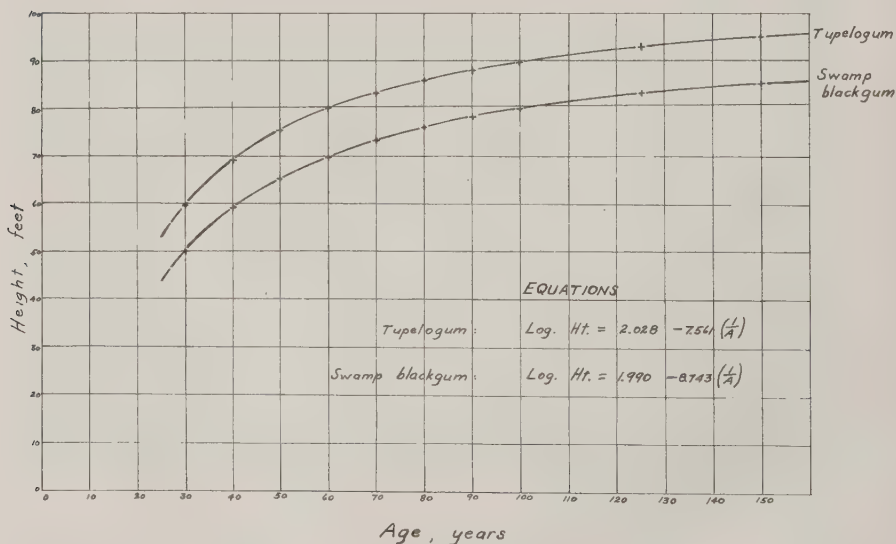
Figure 5. Height of the dominant trees as related to age, swamp blackgum and tupelogum stands, ninety plots, southeastern Georgia.

With the regression coefficients at hand, it was then possible to solve for and determine the site index of each plot. From these data the mean site index for each species-site combination was calculated. These averages are presented in Table 3.

TABLE 3. Mean site indexes for swamp blackgum and tupelogum in southeastern Georgia.

Species	Site	Number Plots	Mean Site Index, Feet
Swamp Blackgum	Swamp	37	66.6
"	Run	19	62.8
"	Pond	17	63.7
"	Bay	5	72.9
"	Riverbottom	3	66.8
"	All sites	81	65.4
Tupelogum	Swamp	15	74.4
"	Riverbottom	2	83.9
"	All sites	17	75.4

Site index differences between the different sites were not statistically significant.

After completion of all soil analyses and the assignment of site indexes, tests were made to isolate the soil variables associated with site index. Graphic analysis of scatter diagrams was used wherein site index was plotted as the dependent variable over a soil value as the independent variable. Separate diagrams were made for each species. In this manner, the following nine soil-site variables were tested:

1. Sand percentage in least permeable horizon
2. Clay percentage in least permeable horizon
3. Loss-on-ignition percentage of surface soil
4. pH of surface soil
5. pH of least permeable horizon
6. Antacid buffer capacity of surface soil
7. Depth to the least permeable horizon
8. Texture-depth index
9. Submergence index

The texture-depth index used here was expressed as the ratio of the silt-plus-clay content of the least permeable horizon to the depth to the least permeable horizon. The submergence index was expressed as the

product of two factors: (1) the thickness of the surface organic layer in inches, and (2) loss-on-ignition percentage. Such a submergence index combines both of the important factors determining how "organic" a given soil is and thus suggests the past flooding history.

Unfortunately, none of the above nine variables showed evidence of a clear-cut relationship to site index. Two variables suggested a fair trend; percent sand in the least permeable horizon was inversely related to site index, while percent clay in the same horizon was directly related. Inasmuch as the sand content appeared to be the better of the two, it was decided to test it, expressed as "silt-plus-clay percentage" for statistical significance.

The final equation resulting from this multiple regression of 51 swamp blackgum plots is:

$$Y = 1.9442 - 6.9372 (X_1) + 0.0746 (X_2)$$

where Y = logarithm height of dominant trees

$X_1 = \dfrac{1}{Age}$

X_2 = silt-plus-clay content of least permeable horizon, expressed as a ratio.

Mean Y in the above equation was 1.902304 with a standard error $\pm$ 0.189. The age variable (X_1) was significantly related to height at the one percent level, but the soil variable (X_2) was just significant at the five percent level. The soil variable accounted for less than seven percent of the total variation in height.

The above regression equation suggests a relationship of considerable interest but limited utility. It appears that the physical characteristics of the lower soil layers play a role in determining site quality. Specifically, the heavier the least permeable horizon, the greater the height growth. Heavy layers retain more moisture longer, whereas sandy layers dry out more quickly. Thus, even the hydrophytic swamp blackgum grows best where soil moisture is most abundant.

Additional data are needed to establish more definitely the height-age relationships for these swamp species. Such work should concentrate on relatively young plots in the 30- to 80-year age bracket, the period of most active height growth. Beyond that, those soil variables affecting the soil moisture regime should be investigated more intensively.

Growth and Yield Data for Swamp Blackgum and Tupelogum

In the course of this investigation, certain volume, growth, and yield data were obtained incidental to the primary objective. Some of these
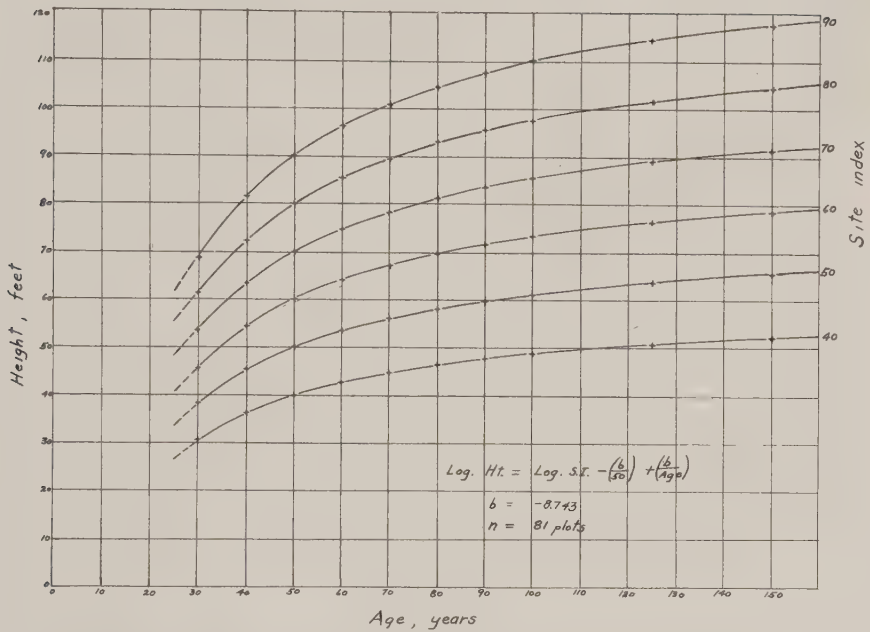
Figure 6. Site index curves for swamp blackgum, southeastern Georgia.
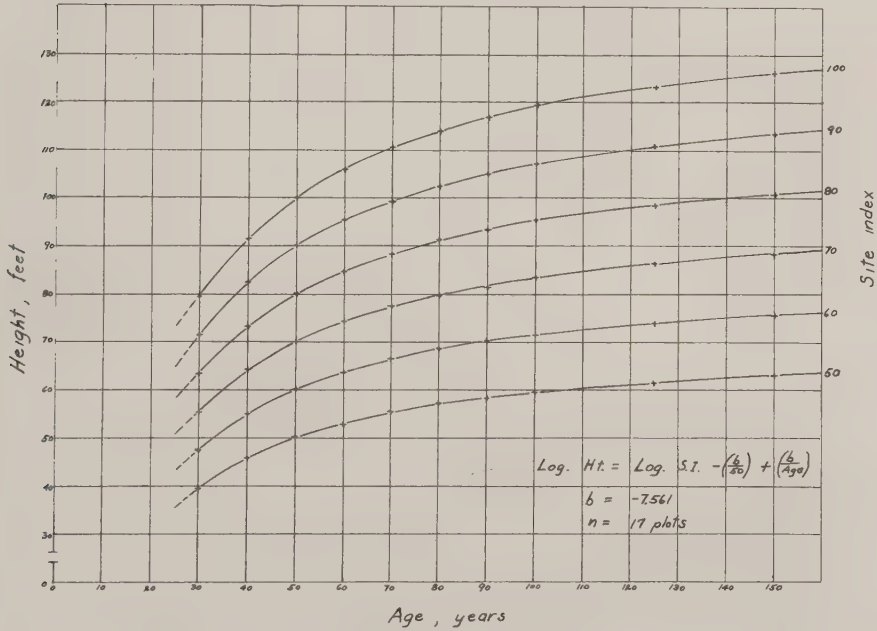

Figure 7. Site index curves for tupelogum, southeastern Georgia.

results are presented here for possible use by foresters managing these
species throughout the South and Southeast.

Site Index Curves

A set of site index curves was prepared for each species in connection
with site index assignments for all plots. The curves and equation for
swamp blackgum appear in Figure 6; those for tupelogum are in Figure 7.

Volume and Yield Data

Volume data, expressed as merchantable cubic-foot volume in trees
5.5 inches in diameter and larger, were available for 80 swamp blackgum
plots and 17 tupelogum plots. These were subjected to multiple regression
analysis using the following independent variables: $\left(\frac{1}{Age}\right)$; $\left(\frac{1}{Age}\right)^2$;
$(S.I.)$; $(S.I.)^2$; $\left(\frac{1}{Age}\right)(S.I.)$; $\left(\frac{1}{Age}\right)^2(S.I.)$; $\left(\frac{1}{Age}\right)(S.I.)^2$;
$\left(\frac{1}{Age}\right)^2(S.I.)^2$. Further tests indicated that the yield equations derived
for swamp blackgum and tupelogum were not significantly different. The
data were, accordingly, pooled and the final equation expressing the vol-
ume relationship calculated as:

$$Y = 3.756 - 17.470 \left(\frac{1}{Age}\right) + 0.00005344 \ (S.I.)^2$$

where: Y = logarithm of the total merchantable cubic-foot volume for
trees 5.5 inches in diameter and larger.

$\frac{1}{Age}$ = reciprocal of age

$S.I.$ = site index

The standard error of Y is $\pm$ 11.05, which represents a 2.53 percent
error when independent variables are at their means.

Solution of the above equation at various ages and site indexes pro-
vided the normal yield table data in Table 4.

The only published yield table data permitting a comparison with fig-
ures in Table 4 are those of Hadley (1926) for second-growth tupelogum
in the Atchafalaya Basin of southern Louisiana. Hadley sampled young
stands 20 to 50 years old which apparently had an average site index of
81.5 feet. His volumes were calculated on a peeled-wood basis, whereas
the present study included bark. Comparisons at ages 30, 40, and 50 for
site index 80 indicate about 1000 cubic feet more volume for the present
study. The bark factor accounts for some of this difference. Further-
more, most of the stands measured in this study were older than 50

TABLE 4. Normal yield table for swamp blackgum and tupelogum stands in southeastern Georgia. Basis: 97 observations.

Age, years	SITE INDEX					
	50	60	70	80	90	100
	Total Merchantable Cubic-foot Volume, Trees 5.5″ D.B.H. and Larger					
30	2028	2322	2725	3277	4039	5103
40	2835	3246	3809	4581	5647	7133
50	3467	3969	4658	5602	6906	8724
60	3966	4541	5329	6408	7900	9979
70	4363	4996	5863	7050	8692	10980
80	4687	5367	6298	7574	9337	11795
90	4957	5675	6661	8009	9874	12474
100	5183	5935	6965	8375	10325	13044
125	5617	6431	7548	9076	11189	14135
150	5927	6786	7963	9576	11806	14914

years; hence, the yield equation would be least reliable in younger age classes and may overestimate volume growth somewhat as Hadley's data suggest.

Radial Growth Data

Incidental to the determination of total age, radial growth during the first thirty years was measured on cores. Averages of these data are presented by species and by sites in Table 5.

TABLE 5. Radial growth during the first 30 years for swamp blackgum and tupelogum sites in southeastern Georgia.

Species	Site	No. Plots	Radial Growth First 30 Years (inches)
Swamp Blackgum	Swamp	37	2.57
″	Run	19	2.76
″	Pond	17	3.16
″	Bay	5	2.52
″	Riverbottom	3	2.60
″	All sites	81	2.75
Tupelogum	All sites	17	3.14

Among the swamp blackgum sites, ponds showed the greatest radial growth during the first 30 years. Growth rings on these cores were also better differentiated and more uniform in width. It is believed that stand uniformity and the scarcity of understory competition played a role in the apparent fast growth of pond stands.

Tupelogum in general made markedly better radial growth than swamp

blackgum. The best plot averaged 4.4 inches during the first 30 years. Individual trees that had grown four to five inches, equivalent to trees 9 inches to 11 inches in diameter, were not uncommon. The fastest growing tree measured was a tupelogum that had produced six inches radial growth in 30 years.

Two other observations concerning radial growth deserve mention: first, the growth for trees of sprout origin, and second, the effects of surface flooding on radial growth.

In connection with increment core analysis work, a group of cores were obtained from swamp blackgum trees which were 14-year-old sprouts. Measurements on these cores indicated an average ten-year radial growth of 2.4 inches inside bark. This is equivalent to about five inches diameter breast high at ten years of age, a growth rate much faster than on any trees from the study plots. While the data are quite limited, they do suggest the possibility of increasing volume growth by sprout culture, especially where pulpwood is an important use.

The effects of surface flooding on radial growth were observed on 14 tupelogum cores from a Tennessee Valley Authority plantation on Wilson Reservoir. This plantation has been described by Silker (1948). He reported good survival after initial planting in 1936 but relatively poor height growth during the early years. During this time, the saplings stood about three feet above normal pool level. Beginning in 1943, the reservoir level was raised so as to flood the plantation one to three feet deep throughout the growing season.

When these cores were examined and measured, it was found that a pronounced spurt in radial growth occurred also in 1943. Ring width for 1943 averaged about seven millimeters; for the previous year it had averaged about three millimeters. Silker (1948) reported a marked increase in height growth for this plantation beginning in 1943. Thus, it seems that these tupelogum trees benefitted by a condition of intermittent to almost-continuous flooding during the growing season.

Stand Structure and Volume Growth Data

Conventional stand data for each study plot were calculated on a per-acre basis. Table 6 summarizes this information by species and by sites for the stand 5.5 inches diameter breast high and larger.

The data in Table 6 provoke much speculation but differences in ages and sites justify only a few generalizations. It is obvious that the stands sampled in this study were relatively old, had relatively large numbers of stems per acre, and supported considerable basal area. Swamp blackgum plots averaged over 200 square feet of basal area and ranged from

TABLE 6. Average stand structure data for trees 5.5 inches D.B.H. and larger, swamp blackgum and tupelogum plots in southeastern Georgia.

Species	Site	No. Plots	Mean Age, Years	Number Trees Per Acre	Basal Area per Acre, Sq. Ft.	Mean D.B.H. Inches	Volume,[1] Trees 5.5" D.B.H. And Larger, Cu. Ft.	Average Annual Growth, Trees 5.5" D.B.H. And Larger Cu. Ft.	Average Annual Growth, Trees 5.5" D.B.H. And Larger Cords[2]
Swamp Blackgum Swamp		37	91	400	225	10.3	6649	74.2	0.99
"	Run	19	82	368	176	9.5	4970	64.0	0.85
"	Pond	17	64	476	201	8.8	5440	87.7	1.17
"	Bay	5	97	238	182	12.3	5989	62.6	0.83
"	Riverbottom	3	92	427	211	9.5	6195	68.7	0.92
"	All	81	84	399	205	9.9	5944	73.7	0.98
Tupelogum	"Pure" stands	9	76	407	252	10.7	7503	98.7	1.32
"	"Mixed" stands	8	113	330	261	12.3	8532	79.5	1.06
"	All	17	94	371	256	11.4	7987	89.6	1.19

[1]All volume figures represent total merchantable cubic-foot volume.
[2]Conversion factor: 75 cubic feet = 1 cord.

a low of 109 to a high of 300 square feet per acre. The 17 tupelogum plots averaged 256 square feet of basal area and ranged from a low of 152 to a high of 435 square feet per acre. Several tupelogum plots had basal areas in excess of 300 square feet. It may be noted in passing that Hall and Penfound (1943) reported a basal area of 481 square feet for a similar swamp near Selma, Alabama.

The volume data in Table 6 become more comparable when converted to an annual-growth basis. Here it is seen that the best annual growth for swamp blackgum occurred in ponds (1.17 cords per acre) and the poorest in runs and bays. When averaged, the 81 swamp blackgum plots grew about one cord per acre per year. Tupelogum growth was definitely better than that for swamp blackgum and averaged about 1.2 cords per acre per year. The nine "pure" tupelogum plots grew about one and one-third cords per acre per year, a figure which agrees closely with Hadley's data for Louisiana tupelogum.

The relatively high densities and large wood volumes attained by these species stand in marked contrast to those for the better known southern pines. Schumacher and Coile (1954) have prepared yield tables for well-stocked loblolly pine in the Coastal Plain. Their figures indicate that swamp blackgum has about twice as many stems, over 40 percent greater basal area, and about two-thirds more cubic-foot volume per acre than loblolly pine at age 80 on an average site (site index 65 feet). A similar comparison for tupelogum 80 years old on an average site (site index 75 feet) reveals that this species has about 2.4 times as many trees per acre as loblolly pine and about 1.7 times greater basal area and cubic-foot volume per acre.

Summary

Much remains to be learned about the growth relations of swamp blackgum and tupelogum. The available evidence, however, indicates that physical soil characteristics which increase the amount of available soil moisture during the growing season also increase height growth. Perhaps of critical importance is the time and duration of floods that occur during the growing season. These and other factors that affect the amount and availability of soil moisture are worthy of more research.

The somewhat common belief that swamp species "tolerate" flooding but actually make their best growth under well-drained conditions deserves critical analysis. Several lines of evidence from this study, as well as other work currently being done on other wet-site species, point up the importance of ample soil moisture during the growing season for maximum growth. It is suggested that the hydrophytic swamp blackgum

and tupelogum may not only tolerate but may literally thrive under flooded or near-flooded conditions.

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GENERAL APPLICATION OF
SITE EVALUATION TO PINE SITES

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Perhaps the most important objective of forest site evaluation is to supply a quantitative estimate of the productivity of forest land. The height attained by the dominant stand at a specified age is the conventional index of site productivity for species that grow in even-aged stands. The significance of this measure of site quality in relation to pulpwood volume production is shown in Figure 8.
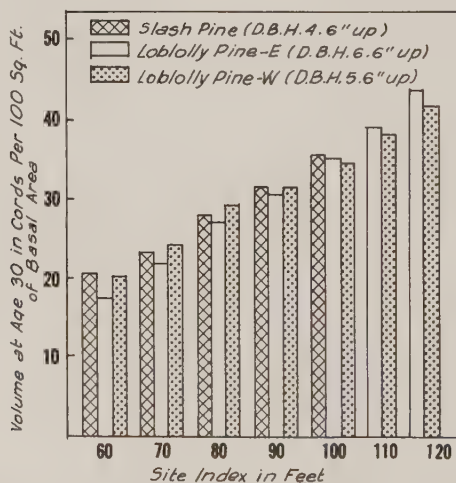
Figure 8. Relationship of site quality to pulpwood volume production for natural stands of (1) slash pine, (2) loblolly pine in the Eastern Coastal Plain (Loblolly-E), and (3) loblolly pine in the Western Coastal Plain (Loblolly-W).

These data — from three separate yield analyses for southern pines (Schumacher and Coile, 1954; Minor, 1958; Ralston, 1958) — show the linear relation of height to yield, if stocking (expressed here as basal area) is constant. It is also interesting to note the rather close agreement in the trends shown, particularly if the slight differences in merchantability limits of the various studies are considered. These comparisons illustrate the range in yield potential that is encountered on pine

lands in the South and are presented here to stress the importance of site evaluation in forest management planning. It is not possible to make an adequate evaluation of most forest land management problems without prior knowledge of anticipated yields, and as shown here the site quality estimate is an essential ingredient of the yield-prediction system.

The role of soil-site evaluation techniques was stated by Coile (1952) as follows:

> "If all forest land was covered with well-stocked stands of sufficient age for the entire solum and upper substratum to have affected their growth, there would be little practical need for studying the relation between soil properties and growth because the volume of wood per acre at a given age would be a direct measure of productivity . . . . Most forest land does not support stands of such stocking and age as to reflect soil productivity in terms of height, growth, or yield. The principal object of studies of soil properties and the growth of forests should be the development of methods for evaluating the productive potential for various tree species of non-forest land (abandoned crop land), cutover, partially cut timberlands, or land that supports very young or very old decadent stands."

In brief, the role of soil-site techniques is to provide a quantitative estimate of site productivity for various land conditions where tree measurements cannot be obtained or are unreliable.

Soil-Site Evaluation Methods

The methodology of soil-site evaluation consists primarily of the development of the evaluation system and the collection and compilation of field data for specific uses or applications.

Development of Evaluation Systems

During the past 25 years a number of investigations have been conducted in various regions of the Southeast to study relationships between site characteristics and the growth of various forest species (Coile, 1935, 1952; Turner, 1938; Goggans, 1951; Zahner, 1954, 1957; Barnes and Ralston, 1955; Dingle and Burns, 1954). These studies report a number of associations of soil, topographic, and climatic variables with site quality. Generalizations from the results of such studies are subject to the restrictions inherent to empirical investigations based on a limited

number of sample observations. These limitations are not serious if the study sample provides adequate representation of the range of site conditions existing in the study area. With proper regard for limiting circumstances, the methods of soil-site analysis can provide the information required for the solution of many forest land management problems.

Collection and Compilation of Field Data

Field survey designs will vary in accordance with the requirements of specific use applications, but, in general, the required site information is acquired by extensive or intensive survey methods.

For many extensive survey purposes an estimate of the mean site index of a tract, compartment, or parcel of land provides the desired information. Ordinarily, the soil data needed for this estimate is obtained from a systematic grid sampling pattern of sufficient density to give reasonable assurance of staying within specified limits of sampling error. These data are collected most efficiently as a part of conventional timber surveys or inventories.

If the site data are to be used for detailed management planning, a more intensive field survey would be indicated. In such cases, mapping of significant soil and topographic boundaries in sufficient detail to permit the separation of areas in each site class or the preparation of site index maps is required. Such surveys are similar to conventional soil surveys on agricultural fields except that under woodland conditions more ground survey control is needed to supplement and verify aerial photo interpretations.

Applications of Soil-Site Evaluation in Forest Management

Knowledge of the site potential of forest land provides the key to the analysis of many questions of management. Some of the instances where this knowledge is particularly useful are described below.

Land Acquisition

In a manner analogous to the determination of stumpage prices, the value of forest land must be derived as a residual quantity. The market price of forest land includes the value of existing forest products and the value of the land itself. Assessment of bare land values expressed in simplest terms usually involves the quantitative solution of an expression of the type:

Bare Land Value	=	Value of potential returns from intermediate and final harvests	—	Periodic silvicultural costs and annual expenses	+	Special ownership premium values

Acquisition inventory data on site and silvicultural requirements provides the information for judging the economic merits of prospective purchase units.

Economic Analysis of Silvicultural Operations

Site evaluation procedures, by providing a means for estimating potential yields, supply the yardstick for measuring the intensity of silvicultural operations. By discounting the future yield values of various site classes to their present value equivalents and by comparing these with known costs of silvicultural operations, various levels of silvicultural intensity can be recognized and used to guide management operations. For example, expensive type conversion and maintenance treatments are not profitable on land of low site quality, while application of the same treatments on land of high productivity stocked with cull trees is very desirable in order to materialize the high profit potential of these lands.

Growth and Yield Prediction

The ability to distinguish differences in site quality can be applied very successfully to problems of yield table construction and growth prediction. This aspect of site evaluation stems from the association of stand height with other stand attributes that determine volume or yield. Specifically, this implies that as a stand increases in height, the number of trees per acre diminish and the average stand diameter increases. These relationships permit prediction of basal area changes associated with changes in stand height. An additional mensurational characteristic, a volume-basal area ratio, completes the system for describing volume production of well-stocked stands.

This system was tested with data from 65 loblolly and shortleaf pine plantations on the Duke Forest and locations in adjacent Piedmont counties. The curves representing average relationships for these pulpwood stands are shown in Figure 9. In addition to the basic data of this study, 32 observations of loblolly pine plantations on Coastal Plain soils of northern Mississippi and Alabama (Ralston, 1958) were plotted on the graphs.
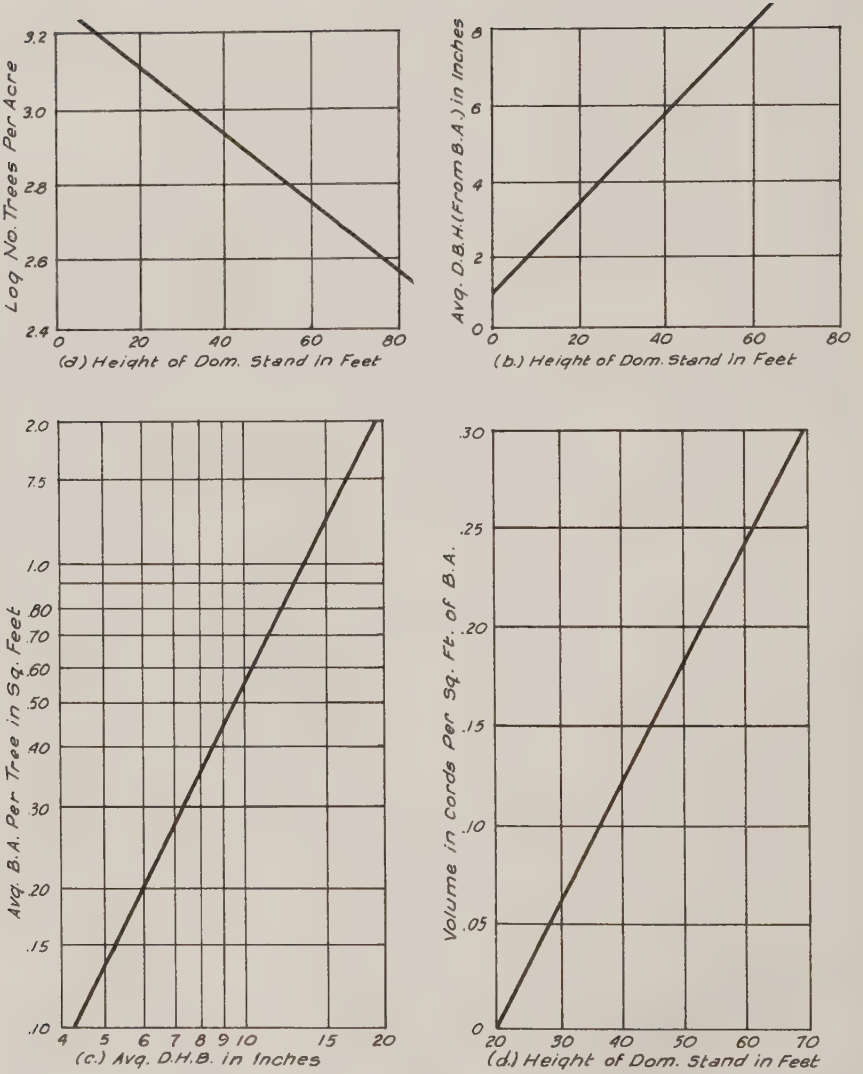
Figure 9.   Average relationships of height, diameter, number of trees, and volume
in loblolly and shortleaf pine plantations.

To prepare a yield table for well-stocked stands from these relationships the following procedure is followed:

1. Determine the height of the dominant stand for any prediction age from the site evaluation estimate and conventional site index curves.

2. Find the number of trees per acre at the desired height (Fig. 9a).

3. Determine the average stand diameter (B.A.) corresponding to the desired height (Fig. 9b).

4. Convert the average stand diameter (B.A.) to average basal area per tree (Fig. 9c).

5. Find the volume-basal ratio (cords per sq. ft. of basal area) for the desired height (Fig. 9d).

6. Compute the stand volume as:
    a. Basal Area = no. of trees/acre $\times$ avg. basal area per tree
    b. Stand Volume 5.5" up (cords) = basal area $\times$ cords per sq. ft. of basal area

The average curves shown here were used to derive the yield values listed in Table 7.

TABLE 7. Yield of loblolly pine plantations in the Piedmont (well-stocked stands).

Ht. of Dom. Stand (feet)	S.I. (50 yrs.)	No. Trees per acre	Avg. Stand Dia. (B.A.)	Basal Area (sq. ft.)	Yield/acre (cords)	M.A.I. (30 yrs.) (cords)
30	38	1000	4.6	113	7.4	0.25
40	51	832	5.7	146	18.4	0.61
50	64	690	6.8	172	32.2	1.07
60	78	575	7.9	194	48.1	1.60
70	91	477	9.0	209	64.4	2.14
80	104	398	10.1	220	81.0	2.70

The yields reported here probably can not be attained on large acreages because it is difficult to maintain stocking over large areas at the levels shown for these small stand fragments. This system of yield analysis may be extended to stands of varying density by the introduction of a variable to permit adjustments for changes in stocking.

Forest Regulation: Allocation of Cut

An example of the use of site evaluation in forest regulation is presented as a final illustration of applications in forest management. A summary of a regulatory system based on a detailed soil-site map of several compart-

ments of the Duke Forest is shown in Table 8 (30-year pulpwood rotation, good pine stocking, and good age distribution are assumed).

TABLE 8. Allocation of cut: site class distribution known.[1]

Site Class	Yield/Acre (30 yrs.) (cords)	Area (acres)	Yield of Site Class (cords)	Size of Cutting Area (acres)	Number of Annual Cutting Areas (Precise)	(Rounded)
50	13	8	104	28.3	0.3⎱	
60	20	27	540	18.4	1.4⎰	(2)
70	27	23	621	13.6	1.7	(2)
80	35	202	7070	10.5	19.2	(19)
90	43	63	2709	8.5	7.4	(7)
	Total	323	11044	——	30.0	(30)

[1]*Computations:* 1. $\text{Annual Cut} = \dfrac{\text{Total Yield}}{\text{Yrs. in Rotation}} = \dfrac{11044}{30} = 368 \text{ cords/yr.}$

2. $\text{Size of Annual Cutting Area} = \dfrac{\text{Annual Cut}}{\text{Yield/acre of Site Class}}$

3. $\text{No. of Cutting Areas} = \dfrac{\text{Area in Site Class}}{\text{Size of Annual Cutting Area}} = \dfrac{\text{Total Yield of Site Class}}{\text{Annual Cut}}$

Research Applications of Site Evaluation

It is probable that site evaluation procedures will be used to advantage in many phases of forest research, but for illustrative purposes, consideration here is restricted to applications in tree improvement and site improvement studies.

Tree Improvement Studies

For tree improvement progeny tests or variety trials it would appear desirable to examine study areas for soil homogeneity or site strata prior to the establishment of experimental plantings.

If replications are few in number, there is a possibility of having variety effect confounded with site differences. This would happen, for example, if all plots of variety number one were concentrated on a good site, and all plots of a second variety were concentrated on a poor site. In this instance, growth differences would be attributed to *varietal* effects, when in fact strong *environmental* growth influences are present.

A statistical design in which blocks are established on each site, and all varieties are equally represented in each block, provides a valid test of varietal effects, particularly if genetic differences are manifest over a range of environments. Soil evaluation appears to be useful in any silvical study where environmental effects are to be minimized.

Site Improvement Studies

The development of the pulp and paper industry in the South as the base of forest management operations has recorded a strong trend of increasing intensity of management. Forest land has been made more productive by raising stocking levels through artificial regeneration and intensive site preparation and improvement of the growing stock itself is the subject of an increasing mass of current research.

Interest also has been awakened to the possibilities of increasing yield by altering some of the environmental factors that affect growth. Excess water in certain coastal wetland areas, and low fertility levels are conditions that can be regulated with fairly low financial investments. However, the economics of these treatments cannot be evaluated properly with current information.

Site evaluation procedures will facilitate research in environmental improvement by supplying a means of identifying and stratifying initial productivity levels of prospective experimental areas. As our knowledge of the interactions of plants and environment advances, the techniques and applications of site evaluation will provide increasing service to the practice of forest management.

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APPLICATION OF SITE EVALUATION
TO A LARGE INDUSTRIAL FOREST

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I feel that I can best cover the topic "Application of Site Evaluation to a Large Industrial Forest" by describing the uses Riegel Paper Corporation is making or plans to make of soil-site evaluation. We have used soil-site evaluation techniques with our own personnel for the past four years; however, this work was not done on a systematic or intensive basis. The information was used in a general way in both land acquisition and land management to avoid mistakes rather than being used as a positive tool in planning. However, in 1958, we obtained the services of a soils consultant to systematically examine our property, interpret the site indexes, and prepare both soils and site index maps. Approximately 50,000 acres have been soils-mapped to date. The site index maps are, of course, delineations on a tract map of the variation in site index. The soils map is a similar delineation but contains, in legend, the drainage class, soil texture, depth of surface soil, parent material, organic matter, and, where applicable, the subsoil consistence. These maps are similar in appearance to timber stand maps.

I believe that a few words relative to the land ownership of Riegel Paper would be appropriate before I outline specifically some of the applications we are making and expect to make of soil-site evaluation. Our land ownership lies in the Piedmont, Sandhills, and Coastal Plain of North Carolina, with the majority of the acreage being in the lower Coastal Plain. The commercial site index range of this property is from 60 to 110 feet. In some instances, this full range is represented on a relatively small area; therefore, generalizations or attempts to arrive at an average site index are not usually applicable. The pine species growing on this land are principally loblolly in the Piedmont, longleaf in the Sandhills, and loblolly, longleaf or pond pine in the Coastal Plain. A considerable portion of our ownership is typical of much of the land acquired by industry within the past few years in that it is cut-over land supporting residual stands of two to five cords per acre. These stands are usually composed of suppressed trees; therefore, site index cannot be determined by the conventional tree-height curve method. In those stands which we now consider to be ade-

quately stocked, past cutting has tended to be in the dominant and co-dominant crown classes, and any attempt to determine site index by tree-height curve would be subject to error. Furthermore, we are committed to a policy of converting longleaf lands to slash and, when economically feasible, pond pine land to loblolly or slash; therefore, the only system of estimating the site index for the conversion species is by soil examination. For those of you not familiar with the habitat of pond pine, this species grows in areas known as bays or pocosins which are relatively flat, very poorly drained, and frequently the surface soil contains varying proportions of organic material up to peat. In its natural state, this land will usually support only pond pine with a site index that rarely exceeds 65 to 70 feet. However, we are convinced that much of this land, if properly drained, will have site index of 85 to 110 feet for loblolly.

On the basis of these stand condition factors, we have made the decision to clear-cut, mechanically prepare, provide drainage where needed, and plant at an average rate of 10,000 acres per year. We estimate that a period of 15 years will be required to accomplish this program, at which time all of our pine land should be either in plantations or in well-stocked natural stands. Our problem, at present, is not what we are to do, but, rather, how to schedule the work each year. It is at this point in our overall forest management operation that we will employ both our soils and site index data. I don't think that anyone will dispute the advisability of scheduling for treatment an area now supporting a stand of two or three cords per acre but capable of producing 3.0 cords per acre per year, mean annual growth, before scheduling an area supporting a similar stand but with a potential of only 1.0 cord per acre per year, mean annual growth. The problem is to know, accurately, where the better land is situated. We are using and will continue to use our site index maps to make these decisions. The soils map is of equal importance since the decision to convert to another species or to provide drainage is based on the soil texture and the drainage class in the case of conversion and on the drainage class in the case of drainage. The decisions to treat, convert, or drain can be made in the office in a relatively short time if adequate soil-site data is available. In the event drainage is required, we can determine from the soils map the acreage of the area to be drained, the lineal footage of ditch required, and arrive at an accurate estimate of the cost of providing drainage. Furthermore, since we can make an estimate of the site index before and after drainage and we know the cost of drainage, we can quickly determine whether the increase in yield is sufficient to justify the expenditure.

Concurrently with the decision to schedule a particular area, we can determine, on the basis of the soil data, the planting spacing to use. Generally, we plant on a closer spacing on the more productive and wetter

sites on the theory that these sites can support more trees at maximum growth. From this spacing data, we can estimate the quantity of seedlings of each species to produce at our nursery, rather than making a general guess of what to produce.

One of the greater benefits that I can foresee for soil-site evaluation will be our ability to estimate quite accurately the total growth capacity of our ownership. There is available today adequate mensurational information in the form of yield tables and growth prediction methods for fully or partially stocked natural stands. There is in progress now a southwide yield study for plantations. However, these data are based on site index and are meaningless for large-scale, specific planning unless we have a definite knowledge of the frequency of occurrence of each site index range. The soil-site survey correlated with the available mensuration data will not only give us a forest management goal to shoot for but will serve as a useful guide in determining the desirable size of ownership, in acres, for our particular conditions. Further, a thorough knowledge of the total productive capacity and the location on the ground of the variations in productive capacity would seem to me to be essential to the establishment of a permanent system of cutting compartments. Any system based solely on acres alone, without giving weight to site capacity, could, in the long run, result in rather serious variations in cut from year to year. A knowledge of the location and acreage of each site index class would provide the basis for establishing a compartment system based on areas of equal productivity rather than on areas of equal acres. Such a system and a knowledge of the yield under intensive management should permit us to predict our cut much more accurately than is now possible. Thinnings will become increasingly important to us in the future; however, without definite knowledge of site quality we could only generalize in a prediction of the thinnings yield from, let us say, 10,000 acres of plantations scheduled for thinning in a given year. For example, we know that some of our sites will yield only one thinning in a 30- or 35-year rotation, while other sites will yield 4 or 5 thinnings in the same rotation. We should be in a position to predict the frequency of thinnings and the volume to be removed at specific locations.

In addition to the purely forest management value of soil-site mapping, the information is useful for such land management activities as location of roads, the type of road construction and the location of wet-weather logging sites. These factors are critical in the lower Coastal Plain since the land is relatively flat and the run-off of surface water is slow. The proper location and method of construction of roads with respect to drainage conditions can mean the difference between having a year-round or a part-time road. I have heard of one company, which has had its lands soils-

mapped, using the soil-texture information to locate soils suitable for road surfacing.

As I mentioned earlier in this discussion, we formerly employed our knowledge of the soil-site relationship in a rather general way to determine the desirability of purchasing a particular tract of land. However, the competition for forest land has increased the price of bare land to a level where we felt that we should be more discriminating in the land we purchase. Poor land, that is, land with low productivity capacity, is priced on a level with the more desirable land. However, we do not feel that we can justify purchasing this poorer land, at current market prices, for the purpose of growing timber. We have, therefore, devised a graduated scale for land acquisition based on site index and the cost of putting that land into production. This system is based on an intensive examination of the soil by our personnel and a knowledge of the costs of establishing stands and managing timberlands. I would be reluctant to go into the details of our calculations, although I am sure that a system of acquisition based on productivity is not unique.

In addition to the technical benefits we have derived and expect to derive from soil-site evaluation, we are now in a position to furnish management with more accurate information on potential growth and yield than formerly and to justify our expenditures on the basis of estimated returns rather than on "guessed at" returns. In other words, we feel that we are now acquiring the information necessary to predict with a fair degree of accuracy what can be accomplished rather than having to rely on a calculation of what has been accomplished after the fact.

SUMMARY OF SOIL-SITE EVALUATION

T. S. COILE, Forest Land Consultant

Since 1954 I have been engaged full time in the forest land consulting business. This involves the application of knowledge gained from research and experience in forest soil productivity and forest management to: (a) the purchase or sale of forest land; (b) the mapping of forest soils and their interpretation in terms of site classes or productivity classes; and (c) general advisory work in the broad field of forest management. My clients are mostly large corporations with ownerships of land up to and in excess of a million acres. They are interested in timber growing purely as a business proposition. Primarily, they wish to be certain of a part of the wood supply for large manufacturing plants such as pulp and paper mills.

Until recent years, few persons in the South, outside of academic circles, were interested in forest soils or forest soil productivity. At least no one was sufficiently interested to conduct or sponsor research. This applied to both federal and state forestry agencies, and to individuals and corporations with large timberland ownerships. In retrospect, this is understandable, because until recently land alone had no value in timberland transactions. Timber, reproduction, and land were purchased primarily on the basis of an estimate of the value of the standing timber alone.

Timberland purchases made up to a few years ago make all the buyers look good now because of the great increases in values of both land and timber. However, much of the early acquisition of forest land would have made the buyers look even better now, had they then known something about forest land quality. Within the past few years, values of timber and land particularly have so increased that we are presently in a "retail" or seller's market. Asking or selling prices for land or soil alone, exclusive of the timber upon it, are relatively high. The present market for land of average quality is usually all it is worth based on any conventional arithmetic. Superior land is still underpriced and poor land is greatly overpriced.

From 1931 to 1953, a period of 22 years, I was primarily concerned with graduate study, research, and teaching in universities. During a large part of this time, I was engaged in, or directed, a broad program of research in forest soils, a large part of which was concerned with measuring the relationship or correlation between a large number of soil properties

(and other environmental factors) and the height-age relationships or site index of natural, even-aged stands of southern pines. This work was done without support from governmental agencies or the wood-using industries. I started it on my own time; later I received a research grant from a privately-endowed foundation, which made it possible to pay traveling expenses and modest wages to many graduate students who worked on the project under my direction. In all of the work I was fortunate to have as a colleague Professor F. X. Schumacher, who directed the statistical analysis of all data. There are several men here that worked on the project, and I am gratified to note that six of my former students are presenting papers.

Present Status of Information for Soil-Site Evaluation

Southern pines

Research on the relation between soil, other environmental factors, and the site index of all southern pines in natural stands except Virginia and spruce pines has probably involved 50- to 60-man-years of work by many individuals. Pertinent work up to 1952 has been summarized in a monograph.[1] This covered the South from Virginia to Texas. There has been some work done since that time in more localized areas in Arkansas and northern Louisiana. Also, work has been done on plantations in Alabama, Florida, and parts of Georgia and South Carolina.

The degree of success attained in demonstrating relationships between environmental factors and growth of trees is largely determined by the investigators' judgment, that is, judgment in selecting the independent variables (soil features, topography, climate, etc.) that are believed to be related to tree growth in various ways and in different combinations. Also, degree of success is effected by heterogeneity or spread in magnitude of the independent variables. For example, one could have a large amount of plot data (including age, height of dominant stand, basal area, and volume), but if the soil or other environmental features covered only a narrow range, it is unlikely that strong relationships could be demonstrated.

How well the investigator samples the entire population of soil and other site factors determines the general applicability of the results.

In our work up to 1953, I believe we got fairly useful results for the effort expended. We did not go at it blindly, with an inexhaustible budget of money and time, and measure every conceivable soil factor. We had a fairly good background of research on soil properties, forest ecology, and tree physiology.

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[1]Coile, T. S. 1952. Soil and the growth of forests. Advances in Agronomy 4: 329-398.

For good reasons we limited our paired soil-forest stand observations to pure, even-aged pine stands over 20 years old (in some studies to over 30 years old), and they had to be fairly well stocked. I believed then, as I still do, that the characteristics of the entire soil profile, to a depth of several feet, do not materially affect the growth of young trees. Moreover, we wanted the heights of the trees in the dominant stand to really represent the capabilities of the soil to grow timber unaffected by stocking and past cutting. These two conditions, minimum age and good stocking, plus the mathematical odds against sampling every possible soil condition that exists, meant that we did not in certain cases sample certain combinations of soil and topography.

Examples of inadequate sampling are:

Slash pine

Estimates of site index had a range of only 15 feet, from 75 to 90, and most of the data were between site index 70 and 95. Most of the soils were imperfectly drained, although they covered a wide range of profile characteristics. We did not sample ponded situations, because the stand appeared overstocked (but perhaps normal for the situation); we did not sample some very extensive wet areas, because between cutting and fire they did not support stands; and we did not adequately sample excessively- and well-drained situations, because of the general absence there of properly stocked stands.

Longleaf pine

Poor, dry sites were not adequately sampled, because the material available was, and is, usually a few longleaf pines and a great many scrub oaks. Hence, they did not meet the stocking requirements.

Superior sites, particularly in the older age classes, also were inadequately sampled. This is partly because really high quality longleaf sites supporting longleaf are geographically localized in three general areas (southern Alabama, western Florida, the lower Piedmont, and East Texas). In these three areas there is considerable land of high site quality for longleaf (90 and 100), but because of the choice quality of the trees for small poles as well as sawtimber, longleaf stands tend to be cut as soon as the trees are large enough. Hence, one does not find many stands of longleaf on really superior soils. One can find a good many stands of longleaf over 60 or 70 years of age of sites 60 and 70, but the chances of finding old stands of longleaf of site 90 and 100 are very poor indeed. Most owners of such stands have usually succumbed to offers to sell. The implications of this situation with respect to the form of site index curves for longleaf pine are clear: little or no data for old, high site-class timber.

Loblolly pine, Coastal Plain

Although data were taken from Virginia to Texas, certain soil and topographic situations were not adequately sampled. This was due largely to the low frequency of pure stands on these situations.

Loblolly and shortleaf pines, Piedmont

The combined study of these two species yielded good results of general application by trained personnel in the Piedmont.

Pond pine

Sampling in the pond pine type generally appears to have been adequate. Many very wet pond pine areas with good soils will be drained and planted to loblolly or slash pines. We can estimate their potential site quality after drainage with reasonable accuracy.

Southern hardwoods, exclusive of the southern Appalachian Mountains

In the absence of specific research results, I believe that site quality for upland hardwoods and some bottomland species can be placed on a qualitative scale of poor, fair, good, and excellent based on the estimated site quality of the land for loblolly pine. Certain bottomland situations, however, because of drainage, overflow, or submergence, cannot be considered as loblolly sites although they represent a wide range of site classes for various hardwoods.

Bottomland hardwoods

Studies have been made on the relation of site factors to site index and yield of tupelo gum and black gum. Also, some work has been done on willow oak. It is apparent that much more work needs to be done with respect to hardwoods generally.

Application of Soil-Site Evaluation to Management

If a large proportion of forest lands were covered with well-stocked stands of the proper age and the proper species to reflect the land's capacity to produce the most useful product, we would not need to know anything about soil and site quality. Very little forest land in the South meets these specifications. By far, the most of it is woefully understocked, or too young to reflect true site quality, or composed of species or types not commercially desirable.

We will never know all we would like to know about soil-site relations

for southern pines. However, we have enough research results to form the general structure of soil-site relations. Some results need to be modified for local situations.

My organization has examined soil and interpreted site quality in all of the southern states, and we have made soil-site surveys (maps) in most of the southern states. We modify or revise existing soil-site tables for local conditions. For example, I use a soil-site table for slash pine that combines five variables, whereas in the original work only one variable appeared significant. Likewise, for both loblolly and longleaf pines, I have constructed new soil-site tables containing more variables and new estimates of site that are peculiar to specific areas.

I will cite the following examples of some of the ways in which soil-site information can be used:

Forest Land Acquisition

The investment method of appraising the value of bare land is appropriately applied to forest land. Concepts of value based on (1) what you can get for it, or (2) comparable sales between a willing buyer and a willing seller, are not presently directly adaptable to forest land for the careful investor. Sellers of timberland now have knowledge of volume and stumpage values on a competitive market. However, within a given locality, the common opinion is that cutover land is worth a certain amount per acre. As a result, although the average site quality might be 80 and worth $30 an acre (or some other figure, poorer land is greatly overpriced and superior land is underpriced). Unfortunately, in the case of forest land, the distribution of sites on a given property is not symmetrically distributed about the mean, as it may be for a large region.

In order to apply the investment method to forest land, one needs to know the following things:
1. Acreage in each site class
2. Future yields and values of products under the proposed level of management
3. Costs
4. Interest rate

Forest Management

Soil-site maps are desirable for intensive, or even moderately intensive, management of forest land. These maps show the specific geographic extent of soil features and forest site classes useful in determining or making decisions on such things as:
1. Selection of species and spacing
2. Prediction of future yields

3. Drainage
4. Site preparation methods
5. Road construction
6. Definition of areas for seasonal logging
7. Allowable costs for all phases of management based on expected returns

Who Should Make Soil-Site Evaluations?

I used to believe that every forester could readily be trained to make soil-site examinations, and even to make soil-site maps. However, experience in recent years has changed my views on this materially. My present views are as follows:

Soil-site sampling for land acquisition

Foresters and others who are willing to learn, are interested, and who are willing to do rigorous physical work can be taught to properly examine soil profile characteristics and other features of the land related to site quality. Because the layman's judgment of certain variables may change without his knowing it, and because seasonal or varying rainfall and other factors may cause his judgment to become unreliable, he needs expert on-the-ground training and periodic orientation. Where relatively large areas are involved, I prefer to do soil-site sampling for acquisition with my own staff, because it is more accurate and less expensive to the client than training and supervising company personnel. However, I have some clients located in regions where most properties offered for sale are small (under 200 acres); in some of these cases I attempt to train and supervise company personnel in the recognition of at least very striking soil features that may indicate a poor, good, or superior site.

I know of one company, who, after three or four days of field instruction on the recognition of soil-site features to a limited number of men, spread the "word" to their entire and large field personnel over many states. Some years later I found that their field crews recognized two textural grades of soil, *i.e.* sands and clays (there are 12 grades). They tended to overestimate site quality by about 15 feet, with the explanation that the main office would not buy land unless it was classified as "good." One field man confided in me that he did not use a soil auger anymore because it was hard work, but he guessed at the soil and site!

Soil-site mapping

Soil classification is a science, whereas soil mapping, to a certain extent, is an art. I believe that soil mapping is a full-time job for properly trained and supervised men. Not everyone has the ability to make good forest

stand condition maps or topographic maps, specially without the aid of photographs. Soil mapping is much more difficult than stand mapping because one cannot "see" below the surface of the ground without making borings, and a man can make only a certain number of borings per day and at the same time cover some ground. As you may have noticed, I said soil mapping instead of soil-site mapping. I expect my field men to map soils alone, with an auger, and not spend a lot of time looking at tree heights and guessing what the soil might be. In my small organization, I spot-check the soil surveys and interpret the soil mapping units into site classes for the various trees that can or should be grown on the land.

I use an open mapping legend and map all features of the soil, drainage, parent material, and topography that I know to be, or believe to be, correlated with tree growth. Many of these characteristics are useful for making other decisions in forest management.

We use aerial photographs as base maps for orientation on the basis of details that can be seen on the photographs. One man can map from 300 to 700 acres per day. Site class delineations are of sufficient accuracy for intensive forest management of large properties.

Specific Comments on Papers Presented at this Session

I hope that you will understand that the following comments about Soil Conservation Service methods are not meant to be materially colored by the fact that I am competing with the U. S. Department of Agriculture in the mapping of forest soils for purposes of forest management.

Soil mapping as practiced by the Soil Survey in the Soil Conservation Service of the U. S. Department of Agriculture has developed over the last 60 years or more. In their system of classification and mapping, I believe they look upon the soil type as a specific dynamic entity which in itself is worth classification and mapping as a science and art alone. They are concerned with the science of soil genesis, morphology, and classification. Their soil surveys and resulting maps are *practices* in trying to delineate in cartographic form various soil bodies. Basically they are not utilitarian. They are science and art for the sake of science and art; they are an exercise. They were not designed to be directly useful even in conventional agriculture. Whereas some elements of conventional soil surveys have been useful in agriculture, their usefulness has been the result of experience and agricultural research; these elements were not deliberately recognized in soil surveys because of their potential practical value.

In attempting to assign average site index to various soil types, the Soil Survey assumes that the soil type has specific meaning with respect to tree growth. This is not borne out by facts. The range of properties allowable

for the modal soil type is so broad in many cases that several 10-foot site classes may occur on the soil type as a mapping unit.

Soil profile examinations for soil surveys used to be made with a 36-inch auger. A few years ago the Soil Survey decided to standardize on a 42-inch auger. The addition of six inches to the length of the auger opened, literally, whole new worlds of soil profiles. Many new soil types were found. The 42-inch auger is too short for making soil survey over much of the South.

In the soil surveys that we make for the purposes of forest management, we use 4-foot and 6-foot augers in the Coastal Plains and sometimes make even deeper borings. The depth to which a boring is made is determined by the combination of soil profile features that are found. We map soils for a purpose, that purpose being the growing of timber.

There is not sufficient time here to go into the details of soil-site research, particularly regression analysis, which Professor Hodgkins appears strongly to condemn. Further, I am not a statistician, and if we were to enter into a debate on the right or wrong way to analyze data, it might develop into a situation of the blind leading the blind, with unfruitful results as far as this group is concerned.

I have discussed Professor Hodgkins' paper with Professor Schumacher, my colleague in research. It is his opinion that this paper brings out nothing that was not considered in our analysis, and that our statistical methods were right and proper for the material analyzed. No one knows more than I the limitations of the original results. I have made thousands of tree measurements and paired site measurements, which have been used to bolster up and fill cells of conditions that were not adequately sampled in our initial and published work.

The general ideas of "total site," or Cajander's "site-types," or plant indicators, have been considered by almost every plant ecologist, and by many foresters for over 30 years. The botanical literature is bulging with long papers on plant communities in relation to their environment. I know of very little work in this area that is useful in forest management. The concepts of "total site" are concerned with qualitative requirements, whereas in our soil-site work we have dealt with quantitative relationships.

I believe that Professor Ralston over-simplified the problems of training and supervising the layman in making soil-site examinations. His example of soil-site mapping is largely of academic value and is useful for student exercises in mapping. His examples of the relation of volume per acre in plantations to basal area, height, and site index certainly will be useful where applicable to older plantations. However, I believe that we are still greatly concerned with the prediction of future yields of plantations on land that is now bare, cutover, or land which involves type conversion.

The paper by Professor Applequist reports the results of entirely new work on two species of bottomland hardwoods. The results were interesting and should be useful in continued work with bottomland hardwoods. I am familiar with the property where he did the field work and understand the difficulty in finding a large number of suitable stands to measure.

Mr. Thornton has cited some actual examples of how his company, Riegel Paper Corporation, uses soil-site information. His company could not possibly justify their intensive forest management without reasonably good information on productive potentials of their land.

In closing, I would like to make these few comments. Forest management is becoming increasingly complicated and separated into areas of specialization. Few practicing foresters can be expected to be highly skilled in a number of specialties. In certain areas, college courses give the student an introduction to a subject, or a bowing acquaintance with it, whereas only years of experience make it possible for the individual to become skilled.

Many foresters, in all position levels, seem to have a "do-it-yourself" complex. They feel that all useful activities in forestry should be rendered so simple that anyone can do them. I believe that this is because they do not like to admit to their "boss" that they do not know how to do a particular job. This may be due to a feeling that in the relative newness and insecurity of his profession, a man must not admit that he does not know how to do something, even if he has to bluff.

FERTILIZING SOUTHERN PINES:
A ROUNDUP OF OBSERVATIONS AND CONCEPTS

LAURENCE C. WALKER, National Plant Food Institute[1]

In the beginning, let me say that the material presented here did not, for the most part, originate with me; but is the accumulation of facts and philosophy garnered from over 300 practicing and research foresters. These foresters represent about one hundred industrial, state, federal, and educational organizations from College Station, Texas, to the Carolina Coast. Obviously, it is impractical and, for me, impossible to record in this paper the origination of ideas and the individuals responsible for reported unpublished research observations and concepts. Quotations from this "Roundup," therefore, should be made with due care lest credit be misplaced.

This is not apology for non-original work. It has been a great opportunity to discuss forest fertilization with so many able practitioners and scientists; but it is an even greater privilege to pass along the wisdom of their words and work. Perhaps from one of these conversational sparks, a great fire of inventiveness may be kindled—even on the other side of the forest.

For a complete review of forest fertilization research in southern forests, to be published in mid-summer (1959) by the National Plant Food Institute, address The Regional Director, Healey Building, Forsyth and Walton Streets, Atlanta, Georgia.

At present there are about 150 experiments in progress on a wide variety of subjects (Fig. 10). Most, however, deal with growth responses of loblolly and slash pine plantations, and the production of seed in orchards and seed production areas.

Information presently being sought on stimulating growth includes the best time to apply fertilizers, in relation to rainfall, rotation age, and fertilizer form; the frequency of application; the relation to irrigation and cultivation; methods of application; and amounts of specific elements required for specific sites.

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[1]Through a special arrangement with the University of Georgia School of Forestry and the College of Agriculture Experiment Station, the author is on an assignment for the National Plant Food Institute, coordinating forest fertilization research throughout the South.
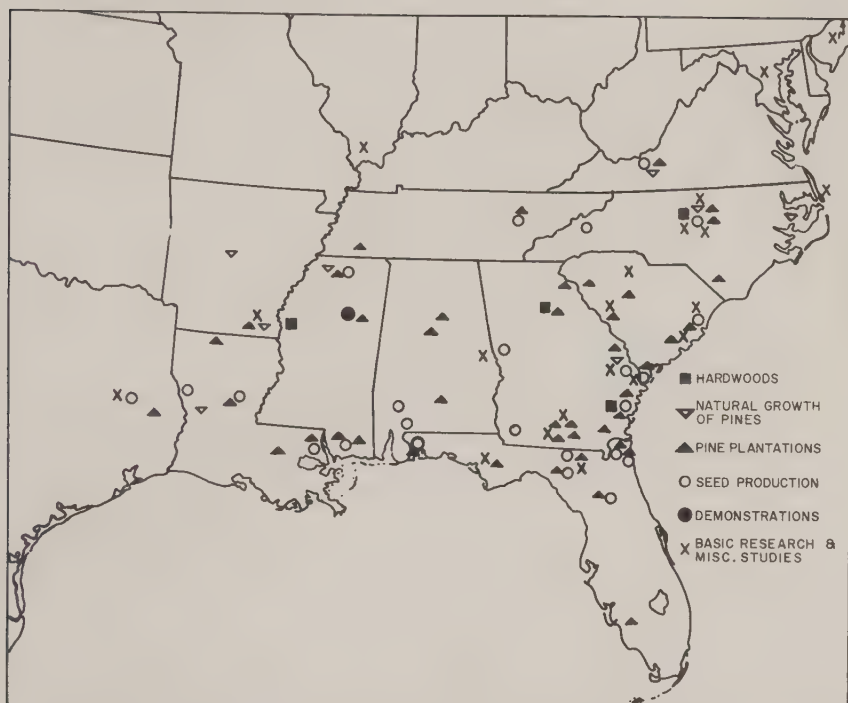
Figure 10. The southeastern United States, showing locations of forest fertilization research installations.

For seed tree fertilization, quality as well as quantity effects are being investigated.

Studies are underway in the fertilization of hardwood seedlings and cuttings, and to see if oak mast production for wildlife food may be stimulated.

Some work deals with foliar analyses—determining the amount of nutrients in needles. It is hoped that such a technique could be employed for indicating deficient sites for southern pines, as it has for low potash soils of northeastern forests (Walker, 1955, 1956). Gum yields and quality effects, disease and insect relations, and Christmas tree color responses are also under investigation.

Many studies are yet to be installed if growth and economic possibilities of forest fertilization are to be realized. A few practical ones, in my opinion, include the following:

(a) Studies to determine if genetic inheritance of strains of each species is an important factor in the efficient utilization of available nutrients for growth. Two adjoining fields, one heavily fertilized and one not, could be randomly planted with five pairs of each of a great

number of progeny from known and control-pollinated seed trees. Obvious superior growth of any one group in the fertilized field in contrast to the check area would be evidence that certain strains react to nutrient applications more favorably than others. Throughout the South, I have seen field studies with an individual stem well above its neighbors, which leads me to stress this hypothesis.

(b) Studies to decide if herbicides can be effectively used in combination with fertilizers for weed control and, thereby, growth stimulation of young plantations. This assumes, of course, that with certain nutrient applications on certain sites, responses will be forthcoming if weeds are checked.

(c) Studies to learn if fertilization in poorly-drained soils, usually requiring drainage, can partly overcome deleterious effects of high water tables. Recently we have found that both slash and loblolly pines were highly tolerant of poor drainage and flooding on a highly-reduced clay soil of the Georgia tidewater area for the first six weeks of their first growing season in the field. Mortality then increased until, by the end of the growing season, most inundated seedlings were dead. Ability to survive under flooded conditions appeared to be related to the height of the terminal buds when flooding began: if buds were above the water line, trees survived. Perhaps additional nutrients can stimulate growth, both before and during natural flooding of plantations (Anonymous, 1958).

(d) Studies to determine if nutrient applications may be related to soil moisture availability in such a way that the effects of drought may be overcome. In the western part of the southern region, summers of low rainfall are frequent and, as a result, seedlings set out the previous winter die. In the Piedmont of Georgia, sporadic rainfall patterns resulting in an average of more than four 2-week droughts per year over the past 65 years of record keeping make tree planting risky. In other areas, two weeks without rain would hardly be cause for a drought label; but the original subsoils of compact clay now exposed at the surface are relatively ineffective in rain water infiltration and storage for subsequent plant growth. This is especially the case since much of the rainfall occurs as short storms of considerable intensity.

(e) Studies to discover if hardwood control prior to fertilization releases sufficient soil water to make the addition of nutrients effective in sites where fertilizers otherwise may not stimulate growth. Undesirable hardwoods are rapidly taking over pine lands in the South. In the Piedmont of Georgia, for instance, one out of every two acres is
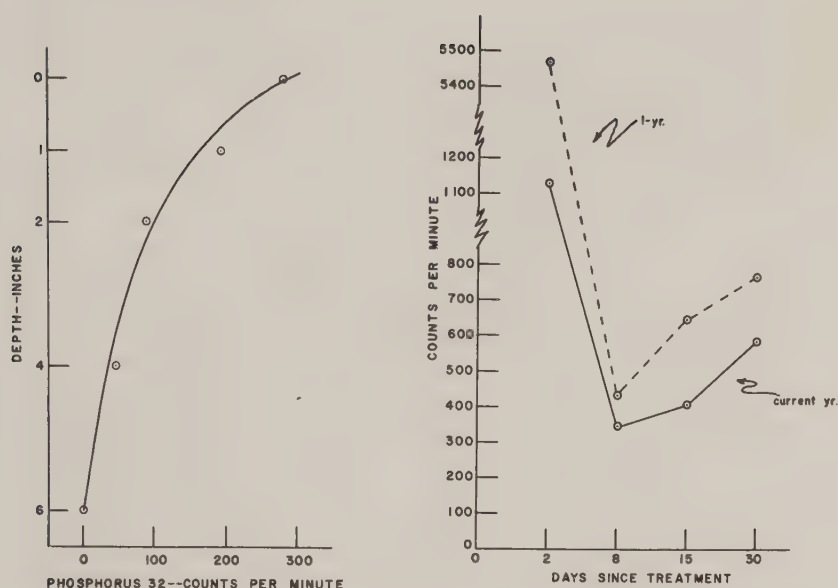
Figure 11.   Radioisotopes are useful tools in forest fertilization studies. The figure on the left shows the depth to which H_3PO_4 migrated fifteen days after application to the soil surface. The right graph shows the uptake of phosphorus in loblolly pine foliage from the phosphoric acid application. Both one-year and current-year needles were analyzed at four periods after treatment. "Counts per minute" is a measure of radioactivity and hence an indicator of the amount of radiophosphorus present.

said to revert to hardwoods after the final harvest cutting. The weed trees among them must be controlled, and will be controlled, probably leaving available water for residual pines. Conceivably, this water may influence nutrient uptake and growth.

(f) Studies to outline root growth patterns of southern pines in various soil types. This is needed to specify where fertilizers should be applied in practice, again assuming responses forthcoming. Perhaps, too, the depth, and distance from trees, at which nutrients are applied may influence response.

(g) Studies to ascertain if foliar analytical sampling techniques can be useful for site evaluation in southern forests. As stated previously, some preliminary analytical work with pine needles is underway (Fig. 11).

(h) Studies to induce favorable auxin-nutrient interactions. Remarkable growth has been obtained with gibberellic acid in at least one experiment, and suggests the possibility of growth regulator-fertilizer combinations.

(i) Studies to learn the recycling rate of plant nutrients in various forest soils. If growth response occurs, the frequency of fertilizer applications will probably be governed to some degree by the rate of organic decay, incorporation of nutrients, and uptake through tree roots.

(j) Studies to determine causes of needle chloroses prevalent among the hard pines. Could a nutrient deficiency, moisture excess, or climate be involved?

(k) Studies to test the effectiveness of seed-tree nutrition on seed storage. Considerable interest is apparent, since much southern pine seed is stored for use in "famine" years.

(l) Studies to reveal if wood quality is related to the nutrient status of southern pines. Even if growth responses to nutrient additions should not prove economically feasible, there is some possibility that wood quality may be improved. This hypothesis must be tested. Fertilization may alter the summerwood: springwood ratio or the cellulose: lignin ratio and, particularly in young stands, may enlarge the center core of juvenile wood. Juvenile wood has qualities inferior to mature wood for pulp. Paul and Marts (1954) present evidence that summerwood was increased with nitrate fertilizer and springwood with a complete fertilizer applied to longleaf pine in deep sandy soils. It should be further determined if tracheid length and wall thickness are altered and resultant wood density changed.

With so many studies underway and so many to be installed, what can we say is known about fertilizing southern pines? It sometimes appears that early fertilization stimulates weed growth to such an extent that weeds compete for soil moisture and seedlings die (Walker, 1958). From work in the Georgia Piedmont, one might suggest that at least two years should lapse before treatment in order for the soil to be more fully occupied by seedling roots. However, if the demand for forest products again turns drastically upward, the possibility of using herbicides on weeds in plantations, in combination with fertilizer, may be appropriate.

McGregor (1957) reported 500 pounds per acre per year of N applied for 4 years with varying amounts of P, K, and minor elements increased growth of slash pine. This species has also responded to 2 tons per acre of colloidal P (from 18-23 percent P_2O_5) in Florida (Barnes and Ralston, 1953). Bateman and Roark (1953, 1957), in Louisiana, obtained increased longleaf growth with 60 ppa N, 60 ppa P_2O_5, and 60 ppa K_2O, but this increase was later masked. Early work in Florida's Norfolk sands also showed a slight response to N-P-K applications in longleaf stands (Paul and Marts, 1931). Addoms (1937) utilized N in loblolly pine pot culture to stimulate growth. Nitrate was most successful

Figure 12. Fertilizers increase needle length of loblolly (left) and shortleaf (right) pines. Can this be an indicator of subsequent volume growth?

in acid soils, and ammonium in nearly neutral soils. Loblolly seedlings fertilized in nurseries with 150 and 300 ppa N exhibited superior height growth when outplanted in the field (Switzer and Nelson, 1956). Nutritionally, Virginia pine behaves similarly to loblolly, according to Fowells and Krauss (1959). They found optimum growth in pots when N was between 25 and 100 ppm and P at 1 ppm. Pond pine is also said to respond to N and P in combinations (Woodwell, 1958). Moulds and Applequist (1957) reported that slash and loblolly pines, introduced into Australia, respond well to phosphorus. Stunted trees there are associated with fused, twisted, scanty, chlorotic needles.

Negative results are in the literature, too; and may be reviewed in an earlier paper (Walker, 1958). Cummings (1941) applied 27 mixes of N, P, and K to shortleaf pine and found no marked superiority in height growth of fertilized trees, due perhaps to burning roots through applying chemical in mattock holes. Auten (1956) reported no significant height growth with various nutrients in North Carolina on pines other than pond pine. Nitrogen may stimulate that species on organic sites.

Evidences of fertilizer responses in southern forests shed beams of optimistic light (Fig. 12). Young stagnated slash pine in a wet site responded well to an application of 30 ppa N, 60 ppa P_2O_5, and 30 ppa

K_2O. This species has also responded to as little as 50 ppa of P_2O_5 in one area, and to 100 ppa of P_2O_5 in another field trial. In pot cultures, the species also responds to phosphorus additions.

Loblolly pine has responded to as little as 60 ppa N. In a pole-size stand on poor sandy soil, growth of 124 cubic feet per acre is reported. On another area, 80 ppa N gave plantation height growth response. Elsewhere for this species, height growth has not been obtained with any fertilizer treatment, but nitrogen applied at rates of 100 pounds per acre resulted in about 25 percent increase in diameter growth the first two years. The difference averaged about 15 percent over a four-year period. Longleaf vigor and survival appeared to have been better in sandy soils where moderate N-P-K applications have been made, but conclusive measurements are not available.

Some forest physiologists believe that a one-year delay in obtaining height growth response to fertilizer applications is inevitable. While for uni-nodal species such as white and red pine, this may be so: one may postulate that this is doubtful for the multi-nodal southern pines since future growth, related to hormonal stimuli in terminal buds, may be just a few weeks off in southern pines. The next growth flush — and flushes may extend through October — may exhibit the growth ability of the present bud. It is doubtful, too, that absorption and translocation of nutrient salts in the xylem are sufficiently slow to delay affecting buds. A fall fertilizer application, on the other hand, may result in such a delayed response.

On several occasions, it has appeared that fertilizing southern pines resulted in diameter growth stimulation, rather than height growth. If this is so, it is likely that form class will be reduced, since diameter growth would not be equalized throughout the bole, and may not be even in the first 16-foot log. Therefore, to obtain a measure of growth response, some foresters are employing d^2h. This value is said to have a linear relation to volume.

It has been suggested that fertilization be delayed until stands of timber are closed and vegetative competition absent. Soil moisture is then conserved for use of treated trees. For the same reason, fertilizers added after undesirable hardwoods are controlled may be more effective than in uncleaned stands. On severely eroded sites, also, low soil moisture may nullify growth responses to fertilizer applications. Yet, while soil moisture may be more critical on these poorest sites, the opinion has been expressed that nutrient status may be even more critical; and therefore, favorable response to fertilization may occur.

The question is frequently asked, "Can fertilizers increase site index?" Since site index is recognized as a *permanent* reference of land pro-

ductivity, based on climatic, physiographic, and biotic, as well as edaphic factors, fertilization may not directly alter it. It may, however, be indirectly altered permanently if added nutrients are sufficiently recycled to create a more favorable habitat for soil organisms, which in turn improve the physical and chemical properties of the soil.

According to the literature, *Cronartium fusiforme* infection may be related to fertilization (Gilmore and Livingston, 1958). As a result of fertilization, I believe, trees break dormancy earlier and thereby provide succulent current year's needle growth, through which the fungus spores enter, when sporidia dissemination may be at its peak. Also, susceptibility may thereby be stretched over a longer period of time.

It has been suggested that a straight line relation occurs between tip moth infestation and nitrogen applications. In experimental work, therefore, it seems essential to control the moths in order to get a true picture of height growth.

Gemmer (1932), Wenger (1953), Allen (1953), and Hoekstra and Mergen (1957) all report some increase in flowering or cone production of several species. Evidence as to which nutrient, if any, may have been the cause is inconclusive. In seed production studies, seed size should be measured, and subsequently related to seedling size. Time of flower-bud differentiation should also be noted in order to establish the best time to apply nutritional supplements.

Several pot culture studies in greenhouses and under shade slats are exploring chloroses and other symptoms, due, perhaps, to nitrogen, calcium, phosphorus, or iron deficiencies. On occasion, these chlorotic conditions have been at least temporarily corrected. Somewhat in contrast, these experiments indicate the lesser nutrient demand of southern pines than of beans and the relatively high rate of nutrient applications necessary to obtain increased growth.

Summary

In contacting foresters and forest researchers across the South, one gathers many interesting ideas, theories, and philosophical concepts. I have endeavored to relay these observations and concepts here. We have talked about published work, meager though it is, with longleaf, slash, loblolly, and pond pine — indicators of fertilizer potential in both wood volume and seed production. We have talked about the effort now underway — that tests are being made to see which elements may stimulate growth and seed production, and under what conditions. We have discussed the need for additional experiments — principally in the realm of genetics, tree physiology, and environmental aspects. We have

philosophized on nodal effects, diameter versus height growth, moisture and fertilizer relationships, the permanency of site amelioration, and the possibility of fungi and insect pests being associated with forest fertilization.

The potential evidence is strong that further research will bear fruit. But, in these closing remarks, it must be said that experimental evidence is insufficient for recommending fertilizer practices in southern forestry. What we need, first, is a tabulation giving growth responses to be expected for each species in stands of various density and on many sites, when fertilized at specified ages, and at specified rates of application.

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THE USE OF IRRIGATION
IN FORESTRY

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In these days when foresters sometimes find themselves unable to justify, on an economic basis, such biologically sound practices as pre-commercial thinning and site preparation, it may seem difficult to consider the use of such an extremely expensive practice as irrigation. If our title "The Use of Irrigation in Forestry" suggests that we may advocate an irrigation ditch down every row of trees and a pump on every forty, let us put your minds at ease. We have no more intention of proposing such a scheme than a forest geneticist, speaking of "forest tree improvement," has of encouraging the use of controlled pollinations in all forest tree seed production. The point we *would* like to make is that irrigation has, like genetics, some potential usefulness in forestry, and that for successful application both depend on a background of fundamental knowledge. Because we have increased our understanding of genetics, we now have effective programs of forest tree improvement. Similarly, if we want to make the best use of soil moisture, be it naturally or artificially supplied, we first have to know how soil moisture affects the life processes of trees.

Irrigation in Research

The Need for Environmental Control

A variety of questions concerning the role of soil moisture in tree life can be most effectively answered through the use of irrigation in experimental work. For example, while estimates of the effect of soil moisture variables on radial growth can be made in natural conditions, the researcher is handicapped by his inability to control the variables being studied. In trying to test a range of soil moisture conditions, he may have to work in different soil types. Such lack of control may decrease efficiency of the experiment considerably, and even obscure the effects of some variables. Thus, for studies of the environmental factors

which affect growth, the researcher who can exert reasonably good experimental control has a definite advantage.

Admittedly some studies involving environmental factors and tree growth may be conducted with seedlings in phytotrons or similar structures providing partial or full environmental control. However, many studies require the use of trees considerably beyond the seedling stage. Under these circumstances plantations can be developed on uniform sites where competing vegetation can be controlled, soil fertility modified, and the soil moisture supply controlled through irrigation and waterproof coverings.

Specific Research Problems

Now, assuming that we are provided with such a site, what are some of the questions which might be answered through its use?

Photosynthate conversion. One of the basic, yet quite practical, questions which we need to answer is this: Do variations in the soil moisture exert any significant effect on the relative proportions of photosynthate that go into respiration, storage products, cellulose, and such supposed metabolic by-products as oleoresin?

Indications are that the answer is "Yes." These effects are important to the forester. For example, top/root ratios in plants are influenced by the availability of soil moisture. It has been shown that if the supply of water is deficient, addition of water usually increases the yields of *both* the roots and tops of the plants (Black, 1957), but the *ratio* of the weight of the above-ground parts to below-ground parts increases with increasing water supply until an optimum point is reached. Thus we might expect that, all other things being equal, we could encourage conversion of a greater amount of carbohydrate to above-ground parts — that is, merchantable wood — by providing adequate soil moisture. Where irrigation facilities are available, the forester could test this possibility on trees.

A related example may be cited for another conversion process, the formation by plants of differentiation products such as gums, essential oils, and alkaloids. Wadleigh, Gauch and Magistad (1946) found that as soil moisture tension increased, the absolute yield of air-dry stems and roots of guayule decreased. However, the absolute yield of rubber remained approximately the same, with the rubber content of the stems and roots increasing from about 4 percent to 6 percent. Thus, although soil moisture deficit reduced growth, it did not decrease rubber production. It would be interesting to know whether soil moisture also affects the relative production of wood and oleoresin in pines.

That soil moisture may be involved in the production of buds, flowers,

and cones of loblolly pine was pointed out by Wenger (1957). He found that May-July rainfall was an important factor affecting seed yield and suggested that it may be possible to promote fruiting by timely irrigation. Gemmer (1932) reported the effects of irrigation and complete fertilizer on longleaf pine cone production in west Florida. Average cone yield on treated trees was found to be 30 times greater than controls after 5 years. Research on seed orchard culture is underway and will be discussed later.

Soil moisture-fertilizer interactions. The wide interest in forest fertilization current in the Southeast has introduced, or reintroduced, the question of the relative importance of soil moisture and mineral nutrients as factors influencing site quality and growth. Since absorption of mineral nutrients is affected by soil moisture, researchers have had difficulty in assessing the independent contribution of each. Split-plot experiments incorporating both fertilization and irrigation will permit separation of the individual effects and their interactions.

A study conducted by the Intermountain Forest and Range Experiment Station (Anonymous, 1958) in northern Idaho has shown the importance of such interactions. In the test, western white pine seedlings were subjected to the following treatments, both singly and in all possible combinations: fertilization, irrigation, and cultivation. Fertilization alone usually resulted in a modest height-growth response in the second growing season after planting, but often caused heavy weed competition and reduced crown vigor. However, when fertilization was combined with either irrigation or cultivation, height growth was almost tripled, compared to controls. Response to cultivation was attributed largely to reduction of competition for available moisture.

While it seems unlikely that lack of rainfall or low moisture-holding capacity of the soil precludes the use of fertilizers anywhere in the Southeast, investigation of this possibility is needed.

Another hypothesis, which to our knowledge has not been adequately explored with respect to forest trees, is that fertilization increases the efficiency of utilization of soil moisture by increasing the yield per unit of water transpired (Black, 1957). Questions such as these may be answered by irrigation studies.

Soil-moisture affects wood quality. As pulp and fiber production increases, we are becoming more concerned about the yield of fiber per cubic foot of wood—a function of its specific gravity. Larson (1957) has convincingly shown for slash pine that percentage of summerwood per ring—hence specific gravity—is not appreciably affected by growth rate. Of particular interest to this discussion, however, is his finding that a considerable part of the variation in summerwood percentage between

plots was related to soil moisture availability. Summerwood percentage was positively correlated with June and July rainfall and negatively correlated with January and February rainfall. The trends found could be genetic in nature, such as the clinal variations found with other traits and species. In any event, irrigation experiments might be used to determine whether or not the effects of rainfall on summerwood percentage can be duplicated artificially.

The ultimate structure which might be affected by environmental factors, of which soil moisture is one, is the cellulose micelle. Just above this level we might consider the structure of the fiber or tracheid. Researchers are beginning to study the properties of these units as they are affected by genetic and environmental factors and to relate them in turn to quality of the product (Dadswell *et al.*, 1959).

Within the last few months, a convenient and highly sensitive technique for measuring fiber strength properties has been developed at Yale University (Jayne, 1959). Using this method Dr. Jayne has been able to calculate the tensile strength of the cell wall material of tracheids and has found different load/deformation characteristics for tracheids produced under different moisture regimes[1].

It is not at all inconceivable that in the future we may be diverting wood into different uses according to the conditions under which the trees were grown. We may find it profitable to modify tree environment according to the product desired, even if the product requires changing the fiber characteristics.

Many problems of practical importance concerning the whole realm of silviculture can best be investigated through experiments in which the environment can be controlled. While provision for soil moisture control under field conditions is expensive, we believe that, since it is such a fundamental factor in growth, it often *must* be controlled, and that the investment in providing this control will be profitable.

Practical Application of Irrigation

While the use of irrigation as a means of promoting growth of forest stands is not likely to become a common practice in the South in our lifetimes, a major portion of the rapid growth of our southern pines must be attributed to the fortunate combination of ample summer rains and long growing seasons. Certainly the South is not characterized by highly fertile soils.

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[1]Personal communication.

Some parts of the world are not so well endowed. Throughout a large part of the Middle East and North Africa, temperatures adequate for growth coincide with low rainfall. It is in these areas that irrigation of forest plantations has reached its highest development (Anonymous, 1947, 1950, 1957; Garland, 1951; Hakim, 1951; Jeyadev, 1956; Kadambi, 1951; Kaul, 1957; Kahn, A. H. *et al.*, 1956; and Kahn, S. A., 1957).

Irrigation is also used in areas where rainfall is usually adequate for growth but may be lacking over short periods. In these circumstances irrigation is restricted to small areas of intensive culture such as nurseries, seed orchards, seed-production areas, valuable test plantations, and plantations of clonal stock having special genetic value.

Since irrigation finds such a limited practical application in silviculture today, the literature on the subject is scanty. The following articles are cited to give some indication of the results obtained by foresters who have tried it.

In 1931 Paul and Marts reported on the results of an irrigation study using mature longleaf pine on the Choctawhatchee National Forest. The treatments consisted of various combinations of irrigation, irrigation plus fertilization, and fertilization alone, applied for three years. All treatments gave some increase in growth but the five irrigation treatments caused the greatest radial growth increase. Biweekly irrigation from March to December gave an average increase of 96.5 percent. The poorest irrigation treatment, biweekly application from July to December, increased radial growth 61.5 percent.

At Crossett, Arkansas, Zahner[2] irrigated 100 loblolly pine trees for five years after planting in 1953. These irrigated trees averaged 30 percent greater in diameter and height than the 100 unwatered check trees. In another experiment at Crossett loblolly pine were grown in 55-gallon drums. One group was watered all season and another only in the spring. After two years of treatment, when the trees were four years old, the seedlings which were watered throughout the growing season were 37 percent taller and 47 percent larger in diameter than the lightly watered trees.

In a recent article Broadfoot (1958) reported on the effects of shallow water impoundment on hardwoods in the Mississippi Delta. He stated that, in addition to the expected increase in acorn production by the oaks, average annual diameter growth after flooding was 100 percent greater than that before flooding in each year.

Weidman and Berriman (1944), working with ponderosa pine in Cali-

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[2]Personal communication.

fornia, spot-watered newly planted seedlings at 3-week intervals the first summer after planting on two sites. Fifth-year survival of watered trees was 72 percent higher than that of unwatered trees on one site and 28 percent higher on the other. On one site height at five years was 4.2 feet for irrigated trees and 3.5 feet for controls, an increase of 20 percent. Heights were not measured on the other site.

Holmbäck and Malmström (1947) reported on the results of diverting water from a nearby stream onto two plots in the lichen-pine forest of northern Sweden. The period of treatment lasted 11 years and, while no figures were given, seedlings were observed to be taller and diameter growth of older trees greater two to three years after irrigation began.

Balsay (1950), reporting on plantations of poplar in Hungary, noted a great effect of irrigation on growth and recommended closer spacing of irrigation ditches. He observed that, "The irrigation ditches at present are 1000 m. apart; but since growth alongside them can be 10 m. high while that 200 m. away is only 3 m. high, ditches at closer intervals are clearly called for."

The North Idaho Forest Genetics Center has several new tests, including a long-term factorial experiment involving both irrigation and fertilization of western white pine. They also have a portable aluminum pipe irrigation system now in operation at one of their seed orchards. Results of these and similar trials elsewhere will soon be available.

What are the possibilities for promoting the growth of forest trees by irrigation in the South? No one really knows. Schopmeyer and Bengtson (1957) estimated a diameter increase of from 50 to 100 percent for the deep sandy soils of northeast Florida based on the results obtained by Paul and Marts (1931). Similar estimates could probably be made for other areas using the results of studies of soil moisture and precipitation in relation to periodic increment.

The possibility that cheap irrigation techniques, such as partial diversion of streams, pumping from streams and/or impoundment could be used on small problem areas or to promote growth in especially valuable stands, needs further testing. The use of irrigation in research should produce valuable results. Certainly some form of irrigation should be considered for the many seed orchards and seed production areas now being established throughout the South.

Irrigation at the Lake City, Florida, Research Center

One example of this type of irrigation use is in the 5-acre seed orchard of high-gum-yielding strains of slash pine currently being established at the Lake City Research Center of the Southeastern Forest Experi-

ment Station. The first attempt to establish this orchard was made in 1955 with grafted clonal material. The failure of that attempt was attributed mainly to drought. In 1956 a ditch irrigation system was installed. Properly used, this system should prevent a recurrence of drought losses and, we hope, will also increase growth and cone production.

Ditch irrigation is among the less expensive methods of supplying water to the soil, but it does have its limitations. We were fortunate at Lake City in the initial selection of our seed orchard site. The soil is a fine sandy loam with a hard organic layer at 18 inches and a clay layer at 40 inches beneath the surface. The upper 18 inches is light-textured, providing a good medium for lateral seepage of irrigation water. The distribution system consists of V-type lateral ditches 18 inches deep, spaced 30 feet apart between the rows of trees, with supply and drainage ditches 24 inches deep at right angles to the laterals. Several small water-control structures were required in 7 of the 13 lateral ditches, with a larger structure in the drainage ditch.

Water is supplied by a 6-inch well, 260 feet deep, and is moved onto the area by a 10 hp. electric turbine pump. Output is 207 gallons per minute—free flow.

The cost for this installation, including ditching, structures, well-drilling, and pump was $3,600, or $720 per acre. However, the pump capacity can irrigate twice the present area. This expansion would cost $700 for ditches and water control structures, which would reduce the cost per acre to approximately $430.

We are not yet sure which of two methods will be used to regulate irrigation. The Soil Conservation Service has recommended the use of several small water-table wells placed midway between the ditches. With this method irrigation would begin when the water table receded to 30 inches below the soil surface, and after the ditches had been filled the water would be allowed to stand until the water table rose to within 14 inches of the surface. Then the area would be drained and another cycle begun.

We prefer, for experimental purposes, to have a little better control and more precise measurements of soil moisture conditions. Hence, we plan to use a commercial type of tensiometer. This instrument measures water tension through the walls of a buried porcelain cup by means of a vacuum gauge attached to the system above ground.

Tensiometer stations will be set up midway between the ditches to measure soil moisture at two depths—6 and 18 inches below the surface. Since most of the water withdrawal is expected to be from the upper soil layers, the starting and stopping of irrigation will usually be governed by readings for the 6-inch depth. The deeper instrument may be useful

mainly when light rains do not penetrate to the 18-inch depth and readings at this level indicate a soil moisture deficit. The range of available moisture for this soil is small—4 percent. It may not be possible to calibrate the tensiometers accurately enough to be consistently sure of measuring soil moisture changes at lower levels of available moisture. The irrigation system has not been operated long enough to give it a fair trial. Other problems may show up as the work progresses.

It should be emphasized that this study was not designed to test the effects of irrigation. The primary purpose of irrigation here is to prevent mortality and get this demonstration seed orchard established and into maximum cone production as soon as possible. Certainly we hope that some gross comparisons of height, diameter, and seed production with similar unirrigated trees will be possible.

To obtain the more specific information needed for intensively managed, special-use areas of the future, planning for a companion study was begun at the Lake City (Florida) Research Center in 1957. This study, now being established, was designed to determine the long-term effects of type of ground cover, fertilization, and irrigation on the growth and gum yields of slash pine. A secondary objective is to provide test material for future fundamental studies which may be superimposed on the basic design.

The experimental area consists of about 13 acres, approximately half of which are under sprinkler irrigation. The area is laid out to include only one soil type—Blanton sand. This soil is a deep, excessively drained infertile sand, and is common in the lower Coastal Plain.

The area was cleared and the soil disked to about 12 inches, and raked to free it of roots. During the installation period, it has been necessary to disk the area frequently to keep down the grasses, particularly Bermuda grass. Because the soil does not permit rapid lateral seepage and because fertilizer treatments are incorporated in the design, the water is applied from sprinklers rather than by the more economical ditches. Water is obtained from a deep well with 6-inch casing fitted with a 20 hp. electric turbine pump. The system has sufficient capacity to provide 2 acre-inches of water to the whole irrigated area (6 acres) in three 8-hour watering periods.

Besides the irrigation feature, the experiment incorporates four fertilizer-ground cover treatments. These will be applied when all the stock has been successfully established and results from complete factorial trials of N-P-K fertilization are available.

At present, establishment is proceeding as fast as planting stock can be propagated. This is a slow process because replication is by clonal stock produced by airlayering. This feature of the experiment, which

provides for one ramet from each of 24 selected clones in each treatment, gives excellent genetic control and requires fewer replications. In effect, by using vegetative propagation we have placed the same tree under a series of different environmental conditions. The value of this kind of material for the fundamental studies proposed earlier is very great.

We hope that establishment of the trees will be complete by the spring of 1960 and that treatment can be started at that time. By 1965 we should have something besides speculation to report.

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IMPROVING SITE QUALITY
BY WET-LAND DRAINAGE

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Of all cultural measures designed to improve site quality for forest production, the one that offers promise of greater and quicker results is drainage or moisture control on wet lands. The significance of this measure to southern forestry is not difficult to grasp. Along the Atlantic and Gulf coasts from northern Virginia to the Florida parishes of Louisiana are some sixteen million acres of forest land too wet either for optimum tree growth or for easy conduct of woods operations. The degree of wetness varies a great deal from the "dismals," bays, and pocosins to savannas, streambottoms, and flatwood ponds. But in at least parts of all these situations, some degree of drainage and moisture control can be expected to bring about substantial increase in the amount, if not the quality, of wood of the species that can be grown on them.

Drainage or *moisture control* (which implies prescribed manipulation of water table levels) for forestry purposes in the South is still in its infancy. Yet it does not seem too optimistic to speculate that this practice will prove as rewarding for forestry as it has for agriculture. Since the late eighteenth century when the first land drainage canals and ditches in the United States were dug, over a hundred million acres in forty states have been encompassed in drainage districts. Many millions of acres, once too wet to be cultivated, have, since reclamation, developed into some of the most productive agricultural soil in this country.

Experiences in Agriculture

Actually, drainage *per se* in the South is not a new activity. George Washington and others back in 1763 surveyed the Dismal Swamp area of Virginia and North Carolina with a view to reclamation of the land. Quite a bit of ditching was done from Virginia to Florida prior to 1860, but none of this, of course, with any idea or objective of forest site improvement. By 1950, land in organized drainage enterprises in the southeastern Coastal Plain totaled approximately 7½ million acres (An-

derson, 1956). By far the greatest acreage of drained land lies in Florida (Table 9).

TABLE 9. Land in drainage enterprises in 1950 in the southeastern Coastal Plain (adapted from Anderson, 1956).

State	Total land in enterprise, 1950	Organized between 1910 and 1919	
	Acres	*Acres*	*Pct. of total*
Virginia	45,460	3,800	8.4
North Carolina	933,657	295,445	31.6
South Carolina	244,568	52,293	21.3
Georgia	20,341	0	0
Alabama	74,472	32,025	43.1
Florida	5,933,918	4,563,505	77.2
Totals	7,252,416	4,947,068	68.6

Excepting Florida, the bulk of the drainage work has been done since World War I, mainly in the twenties and between 1940 and 1950, with considerable additional activity being undertaken in the past eight years but not reported here.

In many early drainage enterprises, the work was promotional in nature, faulty in planning, unsound in financing, incomplete in execution, and ignorant of the inherent capacities of different soil types and classes to drain. Consequently, difficulties and failures were numerous. Recognizing the need for reform, the State of Louisiana in 1940 inaugurated a program of rehabilitating existing drainage enterprises and of helping to develop new ones, a program which requires thorough investigation to determine the need and degree of drainage desired, development of sound engineering, soil management, and land-use plans, and means of financing the work. Other states have considered similar programs and may have inaugurated them since then.

All of these early drainage enterprises were dominated mainly by agricultural and real estate objectives and viewpoints, although some forest land was obviously involved in most of them. Unfortunately in the South there has been no critical evaluation of the effects of the early work on forest growth, or if there has, the results have not yet reached the main-stream of forestry literature.

Some Lake States Experiences

The situation is somewhat better in the Lake States, where at the turn of the 19th century extensive ditching systems were developed in many northern bogs under the mistaken notion that the land would be needed

for agricultural purposes (Zon and Averell, 1929). The work was ahead of its time. The land is still not needed for agriculture, and considering the present difficulties being experienced with surplus farm production, it may not be needed for this purpose for another century or more, or perhaps not at all. In the meantime, several evaluations of the effects of these drainage projects on forest growth have been made, and some additional specific studies of forest drainage have been conducted there. LeBarron and Neetzel (1942) in summarizing the results of the early investigations point out that (a) growth of swamp forests was greatly accelerated by lowering of the water table; (b) maximum acceleration in growth occurred along ditch banks, rapidly falling to zero within a few hundred feet of the ditches; (c) the type of ditching, uniformly deep and in a fixed grid pattern, a mile apart and without regard to minor topographic variations was inefficient; and, (d) that the investment in this type and pattern of ditching could not be liquidated through increased forest growth alone. In subsequent study, they observed two to four-fold increases in growth of northern white cedar in drained swamps; they also observed considerable inflow from surrounding uplands, and postulated that cut-off ditches might be necessary along the swamp margins to reduce such inflow.

Some Finnish Experiences

In Europe, experience with forest drainage is much more extensive, particularly in Finland. The Finnish National Forest Survey shows that swamps cover over eleven million hectares or about thirty-two percent of the land area. The amount of investigative effort that the Finns have directed toward swamp land forestry is impressive; Tirkkonen (1952) lists over four hundred published papers dealing with various aspects of forest swamp drainage since 1900. One of the important outcomes of this research has been a practical classification of various swamp types, showing that on the basis of present knowledge only about a third of the total forest swamp acreage is worth draining, if increased growth is taken as the main criterion or justification. Also impressive is the amount of research which has been conducted toward determining the productive capacity of different swamp types. Even on initially open or very poorly-stocked swamps, annual increments up to nine cubic meters per hectare (equivalent to nearly forty cubic feet per acre) have been obtained on the better types (Lukkala, 1951). Osara[1] indicates that the expected average increase in annual increment from all drained swamp types would

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[1]Personal communication.

equal between two and four cubic meters per hectare, an increase that percent-wise would still be quite significant for the situations in question.

Some North Carolina Experiences

General. As has already been intimated, drainage for forestry purposes in the South, or more specifically, in the Southeast, is a new venture, only a small acreage having been drained up to 1950 (Schlaudt, 1955). Within the past eight years, it is estimated that perhaps a million acres of forest land have been brought under drainage. However, thirty years ago, Dr. J. V. Hofmann, while undertaking to organize the Division of Forestry at North Carolina State College, envisioned the growth potentials that might be realized through proper moisture control in the *pocosins* (those formidable-appearing upland bogs) of North Carolina and adjoining states. He began to take steps to acquire a large tract of very wet land in Jones and Onslow counties in eastern North Carolina and succeeded in acquiring about eighty thousand acres, which have since been named the Hofmann Forest. Some drainage on this forest was undertaken in the mid-thirties with the aid of the Civilian Conservation Corps. The bulk of the canal and ditch excavation, however, has been done within the past fifteen years, initially as an enterprise of the North Carolina Forestry Foundation under the management of Dr. Hofmann, and later under a lease arrangement with the Halifax Paper Company. Within the past ten years, an intensive program of research by the School of Forestry and the Agricultural Experiment Station of North Carolina State College has been under way there. Although numerous questions regarding management of the pocosin types remain unanswered, it seems already clear that Dr. Hofmann's early and unflinching faith in the ultimate productivity of pocosins for forestry purposes was fully justified.

Some research results. The main lines of investigation to date have concerned species trials in afforestation, water table behavior in relation to degree of drainage, and natural regeneration and growth of pond pine. Some tentative conclusions may be drawn from several of the studies at this time.

a. Plantings. The oldest plantings included loblolly and slash pine which are now 22 years old and were last remeasured for growth when they were 19 years old. Within an eighth mile of the canal, the mean annual increment for both species has averaged very slightly better than a cord per acre per year since time of planting. On the same soil type but without any drainage, annual growth of loblolly has averaged only about one-seventh cord per acre per annum (Miller and Maki, 1957).

Tests are under way to determine the productivity of mucks and peats

for growing several species, including pond, slash, loblolly, and longleaf pines; baldcypress; and Atlantic whitecedar. However, these tests have not been going long enough to provide very meaningful assessment of growth differences. It is still not known whether pines, other than the native pond pine, will develop sufficient root systems in deep organic soils to attain adequate wind-firmness. Some Finnish studies have indicated that ninety percent of the root system of Scots pine remains within 10 centimeters of the surface in sphagnum bogs, and that drainage has very little influence on this zonation (Heikurainen, 1955). Ernst (1957) notes marked lack of windfirmness in sapling-size plantations of slash pine and loblolly on high water-table organic soils in Dare County, North Carolina.

b. *Growth of pond pine.* Existing stands of pond pine (*P. serotina* Michx.) in excessively wet situations, and subjected to frequent setbacks from wild fires do not provide a fair picture of the potentialities of this species. For example, the growth characteristics as reported by Kaufman *et al.* (1954) are for typically abused stands of pond pine. A recent evaluation of second growth pond pine performance by Asher (1957) indicates that stands averaging 2,742 cubic feet per acre in trees 3.6 inches in dbh and up, and situated within 900 feet of a drainage canal, have grown at the rate of 108 cubic feet per acre per year over a six-year period (1951 to 1956, inclusive). But the early part of this period included the years when the pines were recovering from a complete defoliation resulting from the great fire of April, 1950, which blackened approximately 50,000 acres of the Hofmann Forest. It seems fair to say that no other pine, southern or northern, could have made such a remarkable comeback in so short a time. When one considers that this growth was attained on land still possibly too wet for satisfactory establishment and growth of loblolly pine, the results seem even more impressive.

So far, our studies of pond pine growth have not given too clear-cut indications of how sensitive this species is to manipulations of the water table through drainage. In one situation where a roadbed formed a barrier to drainage, dominant and codominant pond pines on the roadside plots averaged five feet shorter in total height than comparable trees of the same age on canal-side plots which had been benefitted by reasonably adequate drainage for approximately ten years.

c. *Water table behavior.* Our observations on water table behavior in relation to degree of drainage suggest that some soils cannot be suitably drained, at least not without some strong-arm measures, such as subsoiling. A striking instance of failure to drain is some Portsmouth mucky fine sandy loam situated next to the Roper Road canal; within 60 feet of this canal the water table has remained only ten to twelve inches below

the surface even during the peak of evapotranspiration losses which, inci-
dentally, lower the water table during the growing season on the more
permeable soils to a much greater extent than do the ditches and canals
(Gallup, 1954). (The pronounced influence of vegetation on water table
is similarly illustrated in the report of Trousdell (1955).) Our work has
not progressed far enough to enable determining what proportion of
pocosin-type wet lands cannot be adequately drained because of soil and
other characteristics, but it does not appear that the proportion will be
so high as, for example, has been found in Finland (Averell and McGrew,
1929).

   d. Additional research needs. Beyond the generalization that the prob-
lem of excessive moisture centers mainly around deficient aeration, very
little is known in a basic way about the scheduling and degree of moisture
control for optimum growth of various forest tree species. In mineral
soils we have observed the best developments (*i.e.*, the highest site indexes)
of loblolly and slash pine to occur on imperfectly to poorly drained land,
where the water table during the peak of the growing season may not fall
much below 18 inches of the surface. This depth for mineral soils appears
to be a suitable target to aim for in reasonably permeable soils in situa-
tions where manipulation of water table is feasible.

   Situations where we must deal with organic soils lead us to more dif-
ficult ground. The physical, chemical, and biological characteristics of
organic soils are unique and different from those of mineral soils.

   The task of removing excess water from peats and mucks, if they are
deep enough, presents no special problem, for such soils are permeable
and drain well. The difficult phase of the problem arises in determining
the ideal depth for best growth and how that depth can be maintained
during the growing season; in other words, how readily and successfully
we can manipulate water table levels in a practical way.

   The dangers of excessive drainage of organic soils have been emphasized
occasionally. Postulations that trees on ditch banks have died as a result
of drought in Lake States drainage projects have been proved groundless
(Manson and Miller, 1951). Subsidence is also pointed out as a source
of danger, and in agriculture the subsidence problem is indeed trouble-
some. Spectacular reductions in depth of peat deposits have been re-
corded. For example, the peat soils of the Sacramento-San Joaquin Delta
region have shrunk six to eight feet during a 28-year period, or at the
rate of over three inches per year (Weir, 1950). Some of the deposits
are already ten feet or more below sea level. In Finland, Lukkala (1951)
reports that 35 years after drainage of a forest swamp, compression of
the peat layer has varied between 21 and 41 centimeters, equivalent to
nine to 34 percent of the depth of the deposit. Although subsidence should

not prove nearly so troublesome in forest drainage as it has proved in agriculture, without proper control of water table levels it could conceivably lead to serious difficulties even in forestry operations, quite apart from increased fire danger. But if water table levels can be controlled adequately by a practical system of canal and ditch gates, perhaps subsidence will prove to be a less formidable problem than is now supposed.

The changes that may occur in lesser vegetation as well as in successional trends as a result of drainage is still somewhat of a moot question. In the North Carolina bays and pocosins Buell and Cain (1943) indicated in undrained situations a possible natural succession to hardwoods with *Persea pubescens* and *Magnolia virginia* predominating. They also noted a marked reduction in various brush species as the succession progresses through intermediate stages of Atlantic whitecedar. Sarasto (1952) pointed out that very marked changes in vegetation begin to take place soon after initiation of artificial drainage, and that after about fifty years under Finnish conditions the invasion of the swamp by upland species is complete.

Another problem encountered with organic soils is the possible lack of nutrients in the peat. Malmstrom (1950) pointed out that if the peat deposits are less than 40 centimeters thick, tree roots will reach mineral soil which, if of the right character, can replenish the needed nutrients; but if the peat layer is thicker, and the underlying mineral soil is relatively sterile, a considerable response in tree growth has been obtained by addition of fertilizers. Similar observations on the need for replenishing mineral deficiencies have been made by Huikari (1953) and by Mac-Donald (1953). Wilde and Randall (1949) found that rapid tree growth was strongly correlated with circum-neutral ground water enriched by electrolytes and oxygen.

It is evident from these scattered observations that there are many important areas of investigation which will need attention before sound objectives for drainage and water control practices can be formulated for all the situations where excess water is now a problem. The attempt here has been to emphasize but a few areas of inquiry which may grow more important as work in forest drainage advances beyond the present exploratory stages. It is recognized that no mention has been made here of current work of investigative nature that other schools, agencies, both state and federal, individuals, and the forest industries are conducting. All of this work should ultimately build up the body of knowledge on wet land site improvement in a significant way. The work to date suggests for forestry drainage in the South a promising future but not an easy one.

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SOIL-WATER SHORTAGES AND A MEANS
OF ALLEVIATING RESULTING INFLUENCES
ON SOUTHERN HARDWOODS

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Hardwoods throughout the South have suffered dieback and mortality during recent years. In general, losses have been most severe in cottonwood, sweetgum, and black willow. Some damage also has been noted in red oaks, especially Nuttall; and in elms, green ash, sycamore, and some less important species. Drought is now understood to be the basic cause. Today I will discuss some of the soil and hardwood forest conditions associated with drought, and a means of alleviating the soil-water shortages. Whether the palliative measure is beneficial or harmful to hardwoods depends on how it is applied.

Some dieback was noted in sweetgum over 10 years ago, but its severity and cause did not receive much attention until 1952. In about 1953 abnormal mortality was observed in some stands of black willow. Cottonwood joined the ranks of species suspiciously affected in 1954, after earlier sporadic mortality had been noticed on sandy soils. Other hardwood species on a variety of sites were also dying off rapidly, but it was the severe and sudden losses in sweetgum and cottonwood that focused immediate attention on the problem.

Character of Soil Influences Moisture Supply

Work was started in the South in 1952 toward determining the extent of sweetgum "blight" and its cause, particularly whether a disease organism was involved. Negative results from this line of attack led in 1956 to a study of soil factors. These investigations revealed that certain chemical and physical properties of the soil were significantly related to blight intensity. Dieback was worse on the heavy clays of slackwater areas than on the coarser soils of natural levees. In general, a high proportion of clay or a high concentration of soluble salts (conditions common to the

slackwater soils) tended to be associated with severe blight, probably because these conditions limit availability of moisture.

Not all blight was associated with unfavorable soil attributes, however, and as study progressed it became more and more evident that the probable cause was simply inadequate soil moisture.

In addition to hot weather and lack of rain, some causes of inadequate soil moisture are a build-up of some soil property, such as soluble salts, that tends to increase the tension under which soil moisture is held; physical properties that adversely affect available moisture supply in the root zone; land drainage that lowers water tables; and physiographic conditions in the root-zone (such as topography and stratification) that create obstacles between roots and available moisture. In addition, man-caused conditions unfavorable to ground-water recharge, infiltration, or lateral movement may minimize benefits from rains.

Cottonwood dieback, and accompanying mortality, has been even more sudden and spectacular than sweetgum blight, though it has not been observed over so wide an area. Furthermore, it seems to be much more consistently correlated with soil conditions. Most cottonwood dying has occurred on recent natural-levee soils near the Mississippi River. These soils vary from thin to thick stratified beds of silty clay loams, silt loams, and sandy loams over clays. There are also some deep, excessively drained sands. Stands on sandy sites show the most rapid and severe mortality in dry weather. On the average, sandy soils can hold a maximum of only 6 inches of available water in 5 feet of soil. Without recharge from rain or rising ground water, this amount of soil moisture is used up by well-stocked, fast-growing timber stands in about 15 to 20 days. Since 1952, many forest sites have suffered more than 2 or 3 weeks of drought, particularly in the early part of the growing season.

Siltier soils naturally can store more available water—a 5-foot layer of silt loam can hold, when saturated, about 18 inches. This amount, without recharge, would be a 60-day supply for growing timber. Dieback has been negligible on deep silt loam because droughts of more than 2 months are infrequent.

Poor soil conditions, heat, or lack of rain are not always responsible, of course. Man-caused shortages of water are localized but important. Eroded ridges permit little recharge from winter rains. As a result some soils never reach field moisture capacity even during the rainy season. Deep canals have caused excessive drainage near their margins, and thus have reduced tree growth and have increased mortality in these areas. Along the banks of the Mississippi River asphalt revetments sometimes cover underlying outcrop and lenses, and prevent or deter lateral movement and recharge of ground water when the river rises to root-zone level.

Replenishing Soil Water

Possibly the best means of alleviating water-shortage on the large areas of slowly permeable soils is by impounding water from winter rains, though this is not feasible in some situations. Properly managed surface impoundments help slowly recharge depleted soils and thus increase moisture supply for use by trees during the growing season.

In recent years farmers and sportsmen have built many temporary shallow-water impoundments in southern hardwood forests. The main purpose has been to attract waterfowl, but these forest lakes can also benefit the timber.

The impoundments are generally created by constructing low dikes and dams in flats and sloughs. They are built in time to catch the rains of fall and early winter, as most of the low lands are dry by late autumn. When rains are light or delayed, water is sometimes pumped into the diked areas from wells, streams, or canals. Impoundments in oak woodlands are especially attractive to mallard ducks, which feed on the mast.

As some forest owners are concerned that the water might damage the trees, the Delta Research Center has studied 16 impoundments in Mississippi and Arkansas, representing a variety of flooding conditions. Briefly, the study showed that impoundments increase the amount of water that goes into soil storage; this extra moisture is especially beneficial to trees during dry summers.

A relatively small 160-acre woodland impoundment in Arkansas exemplifies good procedure for using surface water in timber management. The lake is filled to a depth of about 6 to 12 inches by mid-October. It is principally maintained by rainfall in winter until drained in April, by which time the soil below the impoundment contains considerably more available moisture than is found in similar non-flooded soil. In dry summers this additional moisture supply could mean the difference between good growth or practically none.

Borings from representative trees growing in lakes managed in this manner indicate an average diameter growth of 0.4 inch in each of the years since the impoundments were installed. Average annual growth rate for the same trees an equal number of years prior to the shallow-water flooding was 0.2 inch. The fact that dry weather occurred in most years (except 1957) since the impoundments were started, makes the growth difference all the more impressive.

One timber stand of about 700 acres had been flooded from September to April for 14 consecutive years. Diameter growth consistently and uniformly exceeded growth made before the impoundment was constructed. In all stands with this type of water management, tree vigor and acorn

production were found to be excellent. Reproduction was good to excellent in all openings. The seedlings have benefitted not only from the increased soil moisture during the hot, dry summers, but perhaps even more from complete fire prevention from September to April. The shallow water affords protection during the time of year when fire hazard is greatest.

Too Much Water Causes Timber Damage

A word of caution is necessary. In some impoundments the water was left to stand from year to year. After 3 years' continuous impoundment of 1 to 3 feet of water, all forest trees were dead except a very few overcup oak and green ash.

A study was made in a stand that had been flooded continuously for 4 years with less than 12 inches of water. All species had made a surprising spurt in diameter growth during the first year of flooding (Table 10). From there on until the trees died, the reaction varied among species and occasionally within species. Cherrybark oak was the only important commercial species in which occasional trees died at the end of the first year of flooding. In the second year, all cherrybark oaks slowed down in growth and many more died. All elm, sugarberry, honeylocust, and persimmon trees died sometime during the second season of continuous flooding. Willow oak and water oak lasted a little longer; some trees began to decline in growth during the second year, but few died until the

TABLE 10. Diameter-growth reaction since continuous flooding began as compared to that made before flooding.

Forest species	Growing seasons after flooding	Range in growth behavior
Cherrybark oak	1	Most accelerated, but some died at end of season.
	2	Some decelerated, most died.
Elm, sugarberry, honeylocust, persimmon	1	Most accelerated.
	2	Some decelerated, the remainder died.
Willow oak and water oak	1	Most accelerated.
	2	Some accelerated, some decelerated.
	3	Some accelerated, but others died.
	4	Some decelerated, the remainder died.
Nuttall oak, green ash, sweetgum, and overcup oak	1	Most accelerated.
	2	Most accelerated.
	3	Some accelerated, some decelerated.
	4	Some accelerated, some died.

third and sometimes the fourth year. Some willow oak and water oak lasted a little longer; some trees began to decline in growth during the second year, but few died until the third and sometimes the fourth year. Some willow oak and water oak even spurted in growth for 3 consecutive years before decreasing and dying.

Overcup oak, green ash, sweetgum, and Nuttall oak made up the most water-tolerant group. Some trees of these species increased in diameter growth during all 4 years of flooding, while others declined during the third year and died in the fourth.

Variations in reaction within species was probably due to vigor differences and possibly to differences in depth of impounded water. Acorn production stopped after 1 year of continuous flooding, even though the trees sometimes continued to grow in diameter.

In brief, the Delta Research Center's investigations have shown that about 6 to 12 inches of water impounded in September or October and drained in April, if not already used by the timber, will increase the amount of moisture stored in the soil and therefore benefit hardwood growth, especially during dry summers. The impounded water will not damage the trees if it is drained off promptly each spring.

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POTENTIALITIES FOR
IMPROVING FOREST GROWTH

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During the past two days we have heard thorough appraisals of the prospects for the use of individual soil management measures in forestry. I will not attempt to go into any detail in respect to any one of them. Instead, I would like to take a broad look at the question of whether even our best present forests are producing up to the full biological potential of the South. If they are not, then I want to explore how high the biological potential is, and mention a few ways in which we might approach the full potential, without regard to present-day costs. This discussion will be limited to the theoretical biological potential on individual acres. It will not deal with attainable total growth or production for the region as a whole.

Perry and Wang (1957) explored the subject of potential maximum growth at the 1957 Conference on Southern Forest Tree Improvement. Starting with a present mean annual increment of 2½ cords per acre for pine plantations on the best sites in the South, they assumed that this might be increased 85 percent by cultivation (to a total of 4.6 cords), 65 percent more by fertilization (to a total of 6.2 cords), and 30 percent more by genetic improvement (to a total of 8.1 cords per acre per year).

We can approach the same problem from the top down, so to speak, by examining the highest forest production rates that have been attained under ideal conditions, with or without genetic and cultural improvements, in different parts of the world. In order to do this, we first need a scheme for relating the production potential of the climate in those places to the potentialities of our location here in the South.

In 1956, Sten Paterson of Sweden published a book entitled "The Forest Area of the World and Its Potential Productivity" (Paterson, 1956). He studied the relationship of forest volume growth to climatic factors in various forest regions of the world, and arrived at a climatic index which can be used to assess the productiveness for tree growth of a particular climate.

Paterson's climatic index is computed from the following formula:

$$I = \frac{Tv \cdot P \cdot G \cdot E}{Ta \cdot 12 \cdot 100}.$$

Although we do not need go into all of the details of the make-up of this formula, I is the final climatic index, Tv is the average temperature of the warmest month, Ta is a reducing factor representing the annual range in temperature, P is annual precipitation, G is the length of the growing season, and E is a reducing factor for evapotranspiration. The factor E changes the climatic index in inverse proportion to the annual total of solar radiation at that latitude.

The climatic index values computed for forest areas of any size extend from 25 at timberline to 30,000 or more in the tropics. These index values show a fairly close relation to forest production capacity over large areas with present cover. For example, Paterson listed 41 stations for which we have good data on mean annual growth economically attainable under sustained-yield management on large areas, and computed the relation of growth to his climatic index for these areas. The correlation coefficient was 0.90, and the coefficient of determination was 80 percent.

Sample locations with the corresponding production rate and climatic index are given in Table 11.

TABLE 11. Production under sustained yield on large areas, and climatic index of forest productivity for selected stations (from Paterson, 1956).

Station	Site class	Climatic index
	Cu. ft. per acre	
Sodankyla (Finland)	14	83
Tarnaby (Sweden)	31	101
Oslo (Norway)	57	204
Tübingen (Germany)	77	261
Herning (Denmark)	97	313
Wind River (Wash.)	113	700
Olympic (Wash.)	120	1,500
Yaúnde (Cameroun)	168	5,970
Comerio Falls (Puerto Rico)	160	6,200
Sarokka (Java)	164	8,770
Warri Benin (Nigeria)	175	15,100

The table goes only to a climatic index of 15,000 because there are few reliable forest production figures for those tropical areas in which the climatic index is in the range of 20,000 to 30,000. However, extension

Figure 13. Forest productivity zones in the New World based on climatic favor-
ability (S. S. Paterson, 1956).

of the existing yield data with the aid of the climatic data indicates that
the probable regional limit with existing cover and extensive forestry is
about 15 cubic meters per hectare, or 215 cubic feet per acre.

Figure 13 is Paterson's map of forest productivity zones in the New
World, with average productivity translated from the metric units to
cubic feet per acre. The most striking feature is the tremendous area of
very high potential productivity in South America. More than half of
South America is in a climatic index zone of over 1000, corresponding
to a mean annual increment exceeding 130 cubic feet per acre. Because
of the large area of very high climatic index of productivity Paterson
computes that the Central and South American forest region has a total
wood production potential four times that of North America, or about
40 percent of the total forest production potential of the world.

Coming closer to home, our country has only relatively small strips
along the Gulf Coast and Pacific Coast which exceed a climatic productive-
ness index of 1,000. The South has a tremendously larger area of index
500 to 1000 than has the western United States. This fact emphasizes the
South's large share of our national timber production capacity. The chart
also indicates the high potential of cool moist climates as far north as
Vancouver Island and even the Gulf of Alaska. In a more detailed map
of Paterson's climatic index of productivity, the Florida peninsula shows
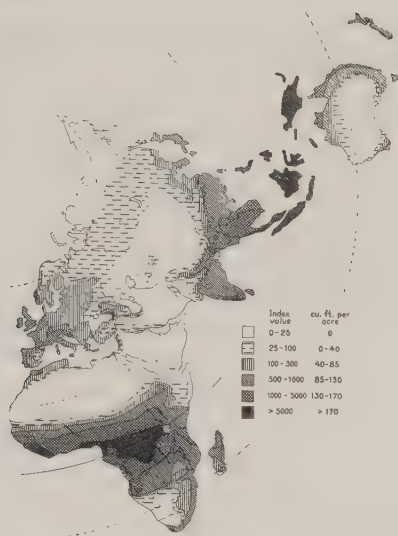up as an area with very high timber-growing potential based on climate

Figure 14. Forest productivity zones in the Old World based on climatic favor-ability (S. S. Paterson, 1956).
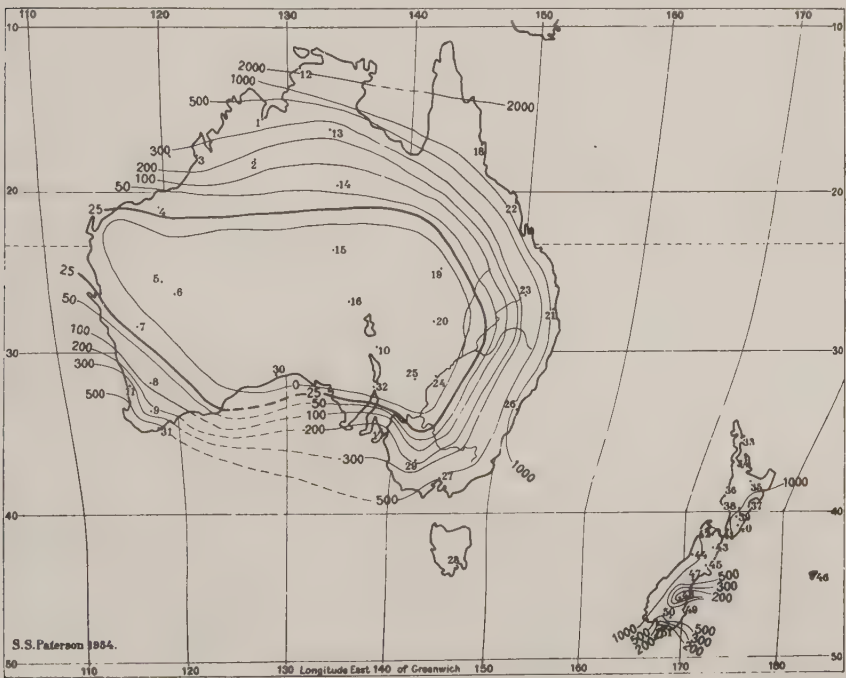

Figure 15. Climatic index of forest productivity in Australia and New Zealand (S. S. Paterson, 1956).

alone. However, this high potential will not be realized without intensive culture to remedy the infertile soils and to control local excesses and deficiencies of soil moisture.

All in all the southeastern United States is the largest and best timber production area north of the Tropic of Cancer, where most of the markets lie. However, the tropical areas of very high potential productivity easily dwarf the temperate areas of this class. Those in the Eastern Hemisphere are shown in Figure 14.

Perhaps you will be interested, as I was, to compare the climatic index of productivity for New Zealand with ours, since they seem to be able to out-produce us with certain tree species. Figure 15 shows several long strips which exceed a climatic index of 1000 in the countries down under, but the only area of index 2000 is in northern Australia. It seems likely that the cooler summers of New Zealand compared to ours in the South favor the maintenance of more fertile soils. Furthermore, their mild winters permit the growing of subtropical species which have higher growth potential than ours. Subtropical pines tend to exceed the pines of our Gulf Coast and of central California in growth rate. We need to explore the possibilities of selecting or developing strains of these high-vigor species that will stand our climate. We also need to intensify our research on breeding the high growth rate of subtropical species into some of our more hardy temperate-zone species.

Paterson's average growth rate of about 200 cubic feet per acre for the most favorable regions is not very impressive when compared with growth rates reported for particularly fertile or foggy spots or for intensive culture. Paterson has collected some data of the latter sort which are given in Table 12.

TABLE 12. Productivity and climatic index of productivity at selected research stations (after Paterson, 1956).

Species	Place	Production	Climatic index group
		Cu. ft. per acre	
Redwood	Big River, Calif.	472	500-1000
Pinus patula	South Africa	406	300- 500
Pinus radiata	South Africa	392	300- 500
Pinus patula	Tweefontein, Transvaal	319	200- 300
Pinus mexicana	Southern Rhodesia	257	200- 300
Spruce-hemlock	Cascade Head, Oreg.	250	1000-2000
Teak	Java	217	1000-2000
Douglas-fir	Columbia, Wash.	200	1000-2000
Pinus mercusii	Sumatra	164	1000-2000

The loose agreement here between the production and the climatic index reflects mainly the differences in intensity of culture or local fertility, but it is evident that extremely high growth rates have been attained in climates less favorable than that of the South. Guided by the data in Table 12 and other information, Paterson prepared the accompanying diagram (Fig. 16) of present and potential forest production rates in relation to the climatic index of productivity. His top line indicates a top potential production of nearly 500 cubic feet per acre per year for the most favorable climate, and a potential of about 350 cubic feet for a climate like that of the South. These figures have already been exceeded in selected instances.
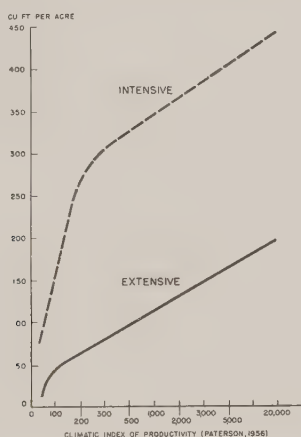

Figure 16. Mean annual increment under sustained-yield management on large areas and potential increment under very intensive forestry (after Paterson, 1956).

In this country, the highest natural production rates occur in the redwood type, with mean annual growth in wild stands of 364 cubic feet per acre on Site I, and current annual growth for selected periods as high as 580 cubic feet per acre (Fritz, 1945). The best stands in the redwood region apparently can produce very close to a quarter of a million board feet per acre at 100 years under extensive forestry.

Next in the West is the Sitka spruce-western hemlock type, where mean annual growth on the best sites is 300 cubic feet per acre at age 70, and current annual growth is nearly 400 cubic feet per acre in young stands. These areas have better moisture relations than the South during most of the year because of their fog-belt location along the coast. Zinke (1959) has shown that a fog-belt location in itself can convey an advantage of as much as 35 feet in site index for Douglas-fir and ponderosa pine, particularly where rainfall is deficient.

Very high production rates are reported from South Africa, where Monterey pine has produced up to 500 cubic feet per acre in mean annual increment to age 34 (Poynton, 1957), and New Zealand, where Weston (1957) reported mean annual increments up to 580 cubic feet per acre for redwood. In southern India, a 15-year coppice rotation of *Eucalyptus globulus* produces a mean annual increment of 537 cubic feet of fuelwood per acre (Thirawat, 1956). If left to grow, the trees reach 175 feet in height at 50 years.

Now let us inject intensive culture into the comparison with other areas that may be approaching their biological potential. But first, I would like to set forth a concept of silviculture which I think embraces the type of practice we will need in order to really approach the biological potential of the Southern forest region. In a recent article, the FAO forestry staff (1958) set forth three stages that silviculture has passed through. First was "classical silviculture" characterized by pure, even-aged stands, operated according to rigid working plans, with well-defined ages and rotations, all backed by mathematical concepts and operated in an almost military fashion. Trees are regarded only as parts of a uniform stand. An example of classical silviculture would be a stand of spruce introduced into the plains of Europe from the mountains.

Biological complications took place which disrupted the automatic application of classical doctrines—soil impoverishment, yield reduction, insect invasions, and difficulties in regeneration.

These difficulties led to the so-called "modern silviculture," in which the biological sciences encroached on the mathematical concepts. The forest was looked on more as a complex of biological associations in equilibrium, in which all factors are important for the well-being of the whole. The individual tree came to the fore as the unit of silviculture. This modern silivculture took us back to nature, and generally favored a natural forest gardened by the selection system.

Now a third form of silviculture, which the FAO forestry staff called "the new silviculture," is emerging. Another name for it would be "creative silviculture." For one thing, some of the climax species favored in the "natural forest" concept of silviculture are either disappearing through the action of man, or their products are no longer required. For another, we are making real progress in racial and genetic selection and hybridization of trees that will make better use of our soils than will our native growth. These new strains cost money, and they usually justify intensive culture to utilize their full production potential. Intensively cultured rapid-growing strains of poplars, for example, have considerably out-produced any of the classical or natural-type stands of the past in Italy and other countries.

Under the new silviculture, we will, in fact, not adapt the forest to the environment—we will adapt the environment to the crop, as we do in agriculture, through fertilization, irrigation, cultivation, or other means. Rather than solve such problems as nutrient shortage, pests, etc. entirely by avoiding them, we will meet at least some of them head-on by fertilization, sprays, and other cultural measures.

This, of course, will mean a much more complicated silviculture, and we can be sure we will have more problems than we have now. The more we learn about new forms of tree crops for use in the new silviculture, the bigger job we will have to do to perfect the most advanced culture for each. Furthermore, our silviculture will have to be tailored to fit in with machine methods in forest production. The extensive areas of level forest land in the South offer one of the best opportunities in the world for the use of large equipment.

With this concept of creative silviculture in mind, what do we know of the biological potential of temperate-zone forests with species selection, genetic improvement, and intensive culture thrown in? First let us take an example involving only very intensive management of the timber stand without any particular soil treatments. By planting 4,000 Douglas-fir trees per acre and thinning them very intensively, the Danes produced $2\frac{1}{5}$ times the cubic-foot increment indicated by our yield tables for the same site index at age 57. Two-thirds of this total yield came from thinnings and one-third from the final harvest. Mean annual yield was 331 cubic feet per acre per year for Site III (Anonymous, 1947).

Now let us take an example involving genetic improvement and intensive culture. Cultivated hybrid poplars on the best sites in the Po Valley in Italy reach 75 feet in height 7 years after planting. At 15 years of age on some sites they average 108 feet tall and 17 inches in diameter. By the time of harvesting at age 25, average dbh is 23 inches and mean
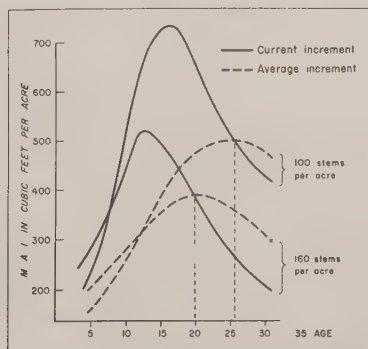

Figure 17. Production of hybrid poplar under intensive culture in the Po Valley in Italy (after International Poplar Commission, 1958).

annual increment for the rotation is 500 cubic feet per acre (Fig. 17).
The better logs are readily accepted for plywood and match stock (Anony-
mous, 1954).

These few comparisons indicate that our growth in the South, even
on well-managed land, is definitely below the biological potential for
this climate. Specifically, we have definite indications that we are lim-
ited by the species we have, by their genetically unimproved state, and
by the somewhat impoverished soils typical of most upland locations in
hot, moist climates. Climatically, we are limited by local or periodic
deficiencies of rainfall during the growing season, and by low winter
temperatures.

Now I would like to take a quick look with you at a few of the pos-
sibilities for improvement through various practices, particularly as they
relate to one another. Probably the most important of all factors in ap-
proaching our biological potential is the selection of a crop that will make
maximum utilization of the soil. Even omitting genetics, we have much
to learn about this. In our enthusiasm for squeezing out more yield
through cultural practices, it is very easy to overlook the less expensive
gains from use of the most suitable species or geographic strain. For
example, a 36-year experiment in Quebec showed that application of 15
tons per acre of manure before planting increased the mean annual incre-
ment of white spruce on abandoned sandy farm land from 26 cubic feet
to 76 cubic feet. However, Norway spruce produced as much without
manure as did white spruce with manure, and Norway spruce with manure
produced 138 cubic feet per acre per year (McArthur, 1957).

Even without soil treatment, the first step toward realizing our bio-
logical potential is to know the relative productivity of the same land for
different tree species. An example is Doolittle's chart of comparative site
indexes for different species growing on the same land in the Southern
Appalachians (Fig. 18). The levels of height growth are reasonably
parallel on different sites for most species, but notice how yellow-poplar
steps ahead of even white pine on the best sites. Because of its sensitivity
to site, yellow-poplar is also a very good index species where it occurs.

The next chart (Fig. 19) shows an extension of the comparative site
index chart to comparative volume production at age 50 based on yield
tables. Although yield tables may not indicate just what we will get under
management, the gross differences check well with related work elsewhere.
All of the pines exceed all of the hardwoods in the area studied, particu-
larly on the average and poor sites. On excellent sites the hardwoods
rapidly grow to veneer size and become a more valuable crop than pines
of equal volume. We have tremendous areas of oak in the East on ordinary
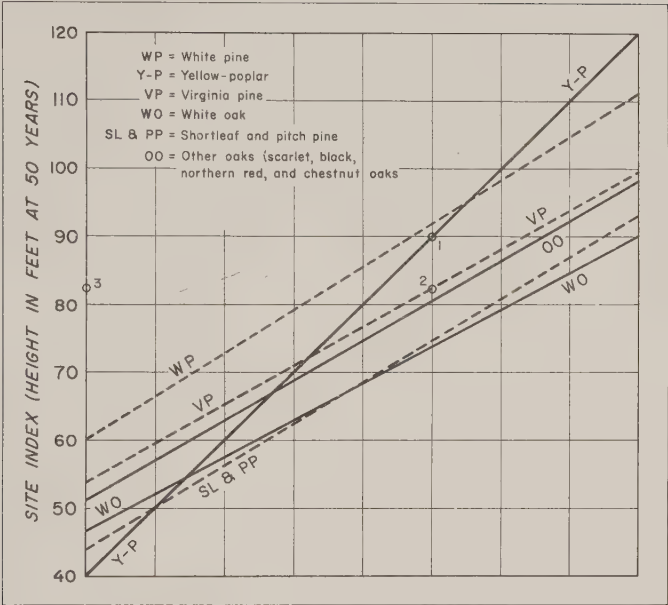sites that would be producing more cellulose if more of the stand were in

Figure 18. A comparison of site indices for ten species on the same land in the southern Appalachians. For example, on land that is site index 90 (1) for yellow-poplar read down (2) and across (3) to find that this same land averages about site 82 for Virginia pine (Doolittle, 1958).
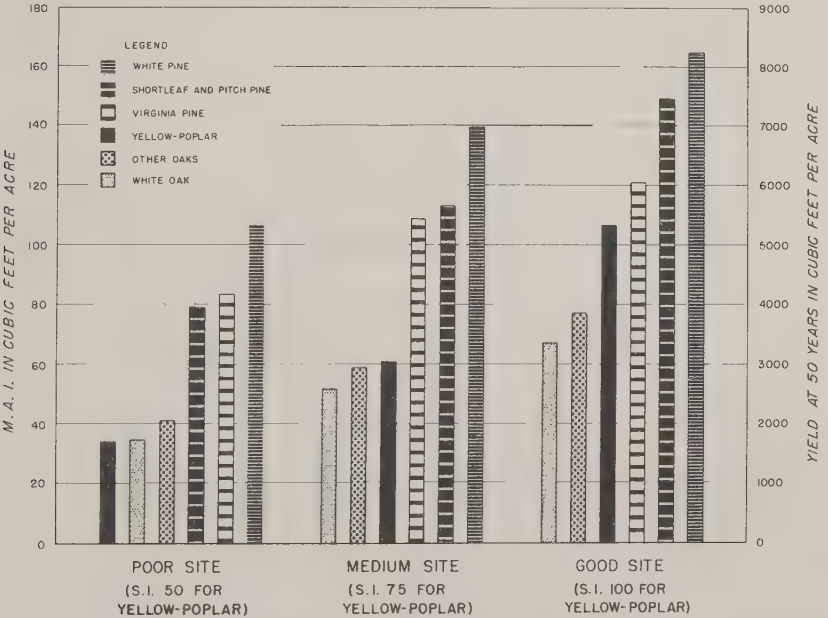

Figure 19. Production of various species at fifty years of age on good, medium and poor sites in the southern Appalachians (Doolittle, 1958).

pine. This is particularly true where we could grow loblolly pine, or white pine toward the southern part of its range where its enemies are not severe. We need to do much more work on the relative growth rates and values of different species on the same land in various localities. This work should pay off handsomely while we are proceeding with the slower job of genetic improvement.

Turning to Europe for another example, mean annual increments in 40 years for different species on second-quality soil in Germany are as follows (International Poplar Commission, 1958):

Species	Cubic feet
Poplar	194
Douglas-fir	131
Larch	97
Spruce	72
Ash	42
Birch	36
Beech	35
Oak	34

If selection of species is the cheapest thing we can do to raise yields, genetic improvement is probably second in this respect. Such developments as irrigation and drainage projects, fertilization, and other land culture require heavy capital investment. By contrast, crop breeding is a comparatively inexpensive job, and once an improved variety is available it represents a long-term investment which pays interest year after year (Silow, 1958).

Some forest geneticists tell us not to expect more than about a 30-percent increase in growth from their efforts, though they do hope to produce distinct benefits in wood quality and in yield of secondary forest products such as oleoresin. Also, it is probable that improved strains may respond better to intensive culture than unimproved ones. Hybrid vigor plus more intensive culture in the use of fertilizers, crop rotation, etc., raised the average yield of corn by 50 percent in a 10-year period ending in the late forties.

A somewhat more expensive way to raise production is through certain types of water control. We have every reason to expect that over the next 100 years new technology will go a long way in this respect. It is all too easy to overlook how far we have come already in water control. An area nearly equal to the entire commercial forest area of the West has been drained for agriculture in the United States. W. H. Keating, who accompanied the Long Expedition in 1823 wrote as follows: "From Chicago to a place where we forded the Des Plaines River the country presents a low,

flat, and swampy prairie, very thickly covered with high grass, aquatic plants, and among others wild rice. . . . The whole of this tract is overflowed in the spring, and canoes pass in every direction across the prairie" (Wooten and Jones, 1955).

Plans have been made or completed for draining nearly a million acres of wet forests in the South since 1950 (Schlaudt, 1955). Much land in the Southeast that could be site 80 or more for slash pine is now producing only a poor swamp forest because of excess standing water. In Finland nearly 2½ million acres of swamp have been drained for forest production, most of it in very recent years since the introduction of specialized heavy equipment.

Irrigation is of course under test. At a cost of $30 to $40 per acre, it promises to yield good returns for special purposes such as seed orchards, where very intensive culture is justified.

Fertilization has been amply covered in this and other recent symposia. It is clear that there is a critical need for much more information from research in this field.

To bring all of this together, the evidence seems to indicate that with improved plant materials and intensive culture, we should be able to produce about 500 cubic feet per acre per year on our very best sites in the South, and 350 cubic feet over broader areas. If this is a correct picture, we have a long way to go in scientific forestry in the next 50 or 100 years.

This of course is a theoretical discussion which explores only the top limits on forest productivity. It is not concerned with the probabilities that our total national wood production will reach any particular level. It does not deal with the economic, operational, and human problems we must solve to reach even the lower goals indicated by present projections of future demand for wood. This discussion has also been limited to volume production, overlooking the importance of dry-matter production and the suitability of fast-grown wood and fast-growing species for specific end uses.

But as we look ahead to a creative type of silviculture aimed at getting production up toward the biological potential, there is one thing we can be sure of—we will encounter many more technical problems than we have now. We will need much more information from research, and we will have a much more complicated technology. Pascal once said that the known is like a circle pushing against the unknown. The larger we make the circle which represents the known, the larger becomes the unknown around it.

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